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ADVANCED INSTRUMENTATION CONCEPTS FOR ENVIRONMENTAL CONTROL SUBSYSTEMS

FINAL REPORT

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P.Y. Yang, F.H. Schubert,
J.R. Gyorki and R.A. Wynveen

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Prepared Under Contract NAS2-9251

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FOREWORD

This report summarizes the development work of advanced instrumentation concepts for regenerative environmental control and life support systems conducted by Life Systems, Inc. during the period of July, 1976 to June, 1978 under NASA Contract NAS2-9251. The Program Manager was Dr. P. Y. Yang. Technical support was provided by F. H. Schubert, J. R. Gyorki, Dr. R. A. Wynveen, Dr. J. Y. Yeh, J. D. Powell, Jr., L. W. Krebs and D. C. Walter. Administrative and documentation support was provided by J. W. Shumar, R. H. Kohler, C. A. Lucas and L. C. DeVito.

Part of the demonstration of the advanced instrumentation concepts was carried out with hardware developed under Contracts NAS2-8666 and NAS9-15218. The support and technical contributions by P. D. Quattrone, N. Lance, Jr. and F. H. Samonski, are gratefully acknowledged.

The program's Technical Monitor was P. D. Quattrone, Chief, Advanced Life Support Project Office, NASA, Ames Research Center.

TABLE OF CONTENTS

continued-

Table of Contents - continued

LIST OF FIGURES

LIST OF TABLES

ACRONYMS

ARS	Air Revitalization System
ARX-1	Air Revitalization System, Experimental, One-Person
ASCII	American Standard Code for Information Interchange
C/M I	Control/Monitor Instrumentation
CRT	Cathode Ray Tube
CS-3	CO_2 Collection Subsystem, Three-Person
CX-1	CO_2 Concentrator, Experimental, One-Person
DVT	Design Verification Testing
EC/LSS	Environmental Control/Life Support System
EDC	Electrochemical Depolarized CO_2 Concentrator
FDIA	Fault Detection and Isolation Analysis
FIFO	First-In-First-Out
GD	Gas Discharge
LRC	Line Replaceable Component
LRU	Line Replaceable Unit
NASA	National Aeronautics and Space Administration
RLSE	Regenerative Life Support Evaluation
RPI	Regulator Position Indicator
TSA	Test Support Accessories
VPI	Valve Position Indicator

SUMMARY

A program to design, evaluate and demonstrate advanced instrumentation concepts for improving performance of manned spacecraft environmental control and life support systems was successfully completed at Life Systems, Inc. An operator/system interface which is an uncomplicated design intended for use by technically untrained personnel has been designed, fabricated and demonstrated. Concepts to aid maintenance following fault detection and isolation were defined and a computer-guided fault correction instruction program designed and demonstrated in a packaged unit which also contains the operator/system interface.

The major accomplishments of the operator/system interface development are:

- Design of a human engineered front panel.
- Design of a logical and easy-to-use message display panel and its display format.
- Development of a unique, dedicated, operator command keyboard.

The benefits of such an operator/system interface include:

- Reduced operator errors by human engineered design of the interface panel.
- Increased value of testing by having more operating information in engineering units.
- Decreased operator time by faster access to performance data and operating conditions.
- Decreased cost of field service by making adjustments available to authorized, on-site test engineers.
- Reduced system development time by allowing easy system/operator information exchange and by commonality in the design.
- Decreased instrumentation development risk by providing flexibility in the design.

The major accomplishments of the maintenance aid study are:

- Definition of fault diagnostic concepts as they relate to environmental control and life support systems.
- Definition of maintenance aid concepts as a part of fault diagnostics.
- Development of computer-based maintenance aids to guide technically untrained personnel in fault correction.

The benefits of the maintenance aids include:

- Reduced system downtime by computer-aided maintenance instructions.
- Reduced operator errors by guided, step-by-step fault isolation and correction instructions.
- Reduced dependence on bulky maintenance manuals by instructions stored in computer memory.
- Reduced operator training by user-oriented instructions.

INTRODUCTION

Regenerative Environmental Control/Life Support Systems (EC/LSS) have been under development for many years.[1-9] The objective is to enable long duration manned space missions to be accomplished. This requires that subsystems which need expendables with large launch weight penalties be replaced by regenerative subsystems for water and oxygen (O_2) reclamation. The regenerative EC/LSS consists of two major systems: the Air Revitalization System (ARS) and the Waste Water Management System (WWMS).

One of the regenerative EC/LSS hardware goals is to allow several years (e.g. five years) of operation before hardware replacement is necessary. In-flight servicing and maintenance will, therefore, be needed. However, the avoidance of excessive crew training requires that maintenance be minimized and aids be provided when maintenance is needed. To accomplish this goal these systems require advanced control and monitor instrumentation.

Background

Life Systems, Inc. has been involved in the design, development and testing of ARS subsystems to remove excess moisture from the air, concentrate carbon dioxide (CO_2) from the air, reduce CO_2 to water and methane or carbon, generate O_2 from water, resupply nitrogen (N_2) and provide N_2 and hydrogen (H_2) separation. In addition, Life Systems, Inc. has also developed a separate Electrochemical Air Revitalization System.[8-13]

An ARS is a complex integration of subsystems containing a range of electrochemical, mechanical and electrical components. The importance of instrumentation is to maintain the desired operating conditions, to coordinate the operation of all these components and to monitor the subsystem performance. It is equally important to recognize that the development of instrumentation should be maintained at a pace consistent with the development of the subsystem's electrochemical and mechanical hardware.

<u>Instrumentation Development Area</u>

Instrumentation development efforts can be divided into the following areas:

---

(1) References cited in parentheses are listed at the end of this report.

1. Integration of subsystems into a complete system
2. Development of instrumentation's interior architecture (processor, logic, memory, input/output, signal conditioner, power conditioner and power supply)
3. Development of test support accessories (TSA) controlled interfaces
4. Development of an operator/system interface
5. Development of system maintenance aids
6. Incorporation of advanced instrumentation concepts
7. Incorporation of the developer's knowledge of operation
8. Development of instrumentation packaging

Figure 1 shows the relationship among these eight developmental areas. Of the eight areas, the program addressed two: development of the operator/system interface and development of system maintenance aids.

Area 1, integration of several subsystems into a system, was completed on independent programs.(10-11,14) This was accomplished through a series of stages including a laboratory breadboard of a Sabatier-based Oxygen Reclamation System for one person using a liquid-cooled Electrochemical Depolarized CO_2 Concentrator (EDC) and a laboratory breadboard using a Bosch-based Oxygen Reclamation System for four persons using an air-cooled EDC.(12,13)

Area 2, development of the instrumentation's interior architecture, was initially defined on a water reuse development program.(15) It was improved upon on the current program. It is necessary to periodically reevaluate the instrumentation's interior architecture and to upgrade it according to added requirements and improvements incorporated in the other development areas.

Area 3, development of the TSA control interface, was completed on prior programs. This consists of the design of the instrumentation used to manipulate and regulate the TSA simulating the spacecraft facility and process air streams including variations in them.

Area 4, development of the operator/system interface, was a natural selection for the current program since, properly done, it can significantly reduce the cost of EC/LSS hardware developments.

Area 5, development of system maintenance aids, while less important during initial development phases, becomes increasingly important as flight hardware is approached. It is a development area, however, that cannot be implemented at "the last minute." Human engineered maintenance aids for regenerative EC/LSS hardware will be an evolutionary process. Little technical data or practical foundations exist. Once an operator/system interface is developed the communication from the system to the operator regarding maintenance requirements can be completed. As Figure 1 shows, the incorporation of maintenance aid information influences the instrumentation's interior architecture; e.g., the size of memory and the number or sequence of inputs and outputs.

Area 6, incorporation of advanced instrumentation concepts, was not selected since instrumentation technology is advancing very rapidly and is considered to have a lower priority than areas 4 or 5. Examples of advanced instrumentation concepts are dynamic performance trend analysis and self-healing electronics for common failure modes.

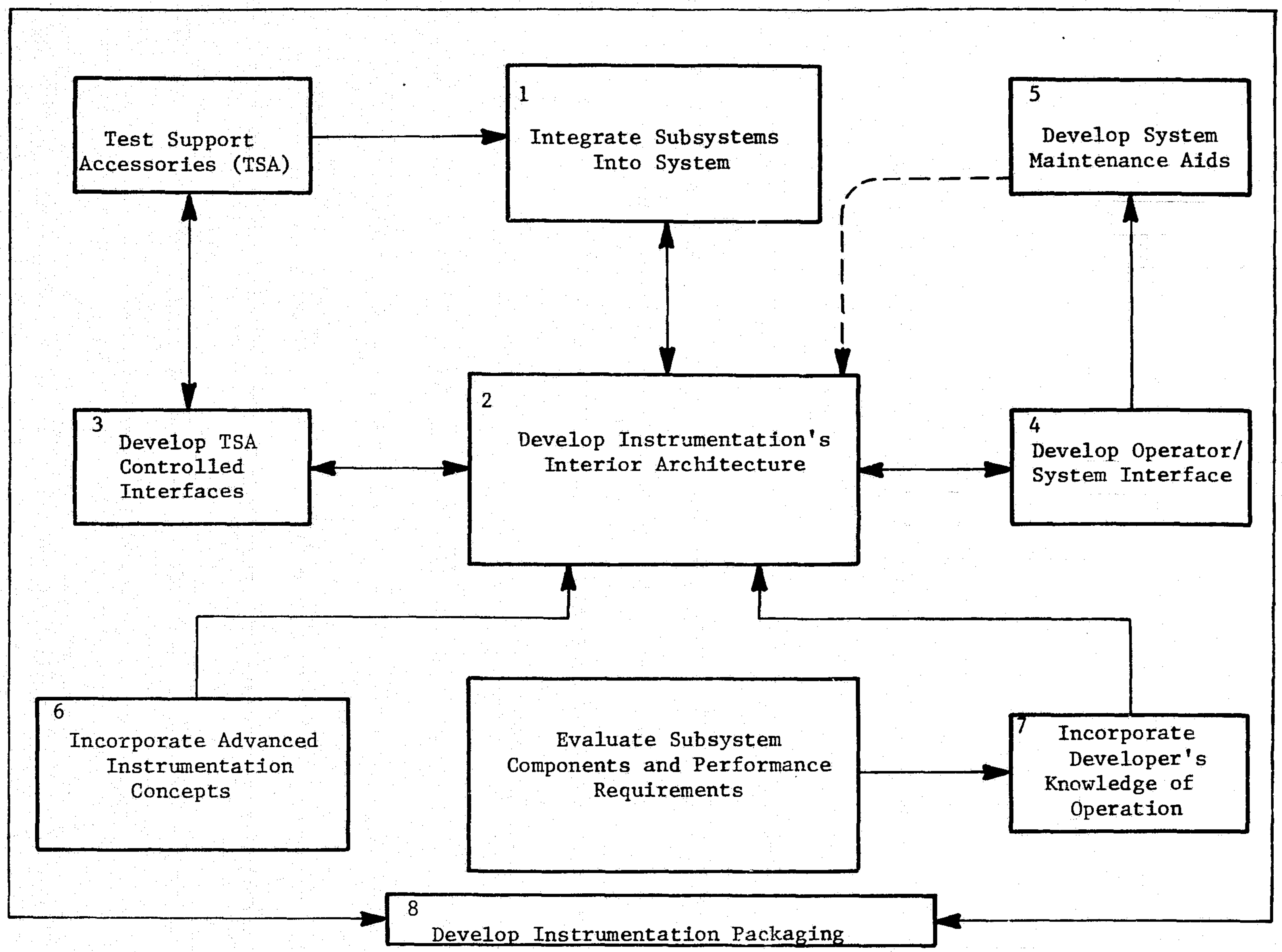

FIGURE 1 INSTRUMENTATION DEVELOPMENT AREAS

Area 7, incorporating the developer's knowledge of operation into the instrumentation, has been planned for future development. It is the area in which the equipment becomes totally independent of the need for the developer's personnel and their intimate understanding of the uniqueness of each of the various subsystems and their interrelationship. This knowledge requires a reevaluation for those subsystem component characteristics and performance requirements that appear infrequently in the course of nominal operation. They are the ones which typically fail to be communicated when hardware, but not operating knowledge, is transferred from the developer to the user.

Area 8, development of instrumentation packaging, was an obvious area to delay. As long as nominal consideration of end-item requirements are included in the development phases, the developed instrumentation should readily be capable of being packaged according to flight specifications and configurations.

Program Objectives

The overall EC/LSS instrumentation development program objectives are to increase instrumentation capacity and reliability while decreasing its weight, power, volume, cost and maintenance requirements.

Design Guidelines

The design guidelines established by the National Aeronautics and Space Administration (NASA) included:

1. Employ commonality of design for lower development cost and lower user cost.

2. Emphasize flexibility and development capability during the development stages while allowing and requiring minimum effort to redesign for dedicated flight hardware.

3. Provide instrumentation hardware and techniques for users that do not have electronics engineering background.

4. Allow expandability and compatibility for continuous upgrading as electronic technology advances.

Program Objectives

The specific objectives of the program were to:

1. Establish the various operator/system interface techniques applicable to advanced ARS hardware, select a preferred technique in light of the guidelines, prepare a description of the recommended operator/interface technique and then fabricate and test a hardware demonstration of the approach. The techniques considered included advanced and current state-of-the-art interface concepts.

2. Establish the various concepts of maintenance aids that could be used to provide fault correction instructions for failures of components or subsystems of an ARS, select a technique, prepare a description

of the recommended approach and demonstrate the approach. This included both aids in fault isolation and correction to the line replaceable unit (LRU) and line replaceable component (LRC) levels.

The objectives of this program were met. The following sections summarize the work completed and the conclusions and recommendations reached.

OPERATOR/SYSTEM INTERFACE

In the development of regenerative EC/LSS, instrumentation characteristics will change going from one development stage to another depending on the unique services a development stage demands. Table 1 illustrates this trend in characteristics for a subsystem going from exploratory development to production. As the development stage moves toward production, there is a decreasing amount or extent of:

- Debugging Effort
- System Downtime -- both Scheduled or Unscheduled
- Flexibility in Operation and Configuration
- Scientific and Development Inputs to the System
- Operator/System Interfaces
- Manual Calibration of Sensors and Actuators
- Weight, Volume and Power Consumption

During the same transition, however, there is an increasing need for:

- Reliability
- In Situ Calibration
- Fault Tolerance

The operator/system interface can be used to illustrate the trend through the development stages. During exploratory and advanced development, the developer's technical personnel as well as the user's personnel will need to make changes in control and alarm setpoints and to interrogate the current operating status of process parameters or components (e.g., an electrochemical cell operating voltage). When the operational and production state is reached control and alarm setpoints will be established, monitoring of process parameters will be automatic with adjustments automatically made if required. Table 1 also shows that the type of instrumentation or level of instrumentation varies going through the various phases of a particular development program. More instrumentation is needed during the debug phase and especially during checkout and shakedown. During design verification testing (DVT) and parametric testing the developer wants considerable quantities of performance data. During endurance testing, however, less data is needed since operational success can be reflected by the continuing performance of the system at nominal conditions or under actual operating constraints.

Upon shipment, the instrumentation remaining in the hardware will meet the requirements NASA has established for the hardware being delivered. It can be technology/parametric-oriented or operational-oriented.

TABLE 1 TYPE OF FRONT PANEL

	Phase of Program								
			Testing						
							Endurance		
	Debug	Integrate Mech. and Elec.	Check-out	Shake-down	DVT	Parametric	Nominal	Real World	Ship

Development Stage

- Exploratory
- Advanced
- Engineering
- Operational
- Production

1. Decreasing Need for Information on Current Step in Sequence
2. Decreasing Need for Override
3. Less Debugging Needed
4. Less Flexibility Needed
5. Less Scientific & Development Inputs

Operator/System Interface Design Alternatives

There are three types of operator/system interfaces:

- Visual Interface
- Contact/Touch Activated Interface
- Audio Interface

Table 2 illustrates some of the interfaces available in each of these three categories.

Visual Interface

State of the art operator/system visual interfaces have already progressed from the use of gauges, meters and switches to shutdown lights, illuminated/annunciator indicators and, more recently, four level indicator lights displaying performance status and trend analysis.[9] An example of this type of hardware is shown in Figure 2.

In keeping with the advancements in electronic technology, however, there are improvements also being made in display techniques. These include cathode ray tube (CRT) displays, gas discharge (GD) matrix message display panels and intelligent displays which change symbol format and manipulate graphic and alphanumeric symbols under computer control. Figures 3 and 4 illustrate the CRT and the GD type matrix display panel.

CRT Display Selected. Of the eight visual interface techniques screened, the black and white alphanumeric CRT display technique was selected for the EC/LSS development level use.

Display techniques employing gauges and meters, illuminated switches and message displays, and graphic annunciator display were eliminated because they provided too little information, required too much interpretation or too high an operator skill level and provided no advanced warning of impending shutdown or the cause contributing to it.

The four-level indicator light display style (Figure 2) represents progress by providing performance trend and fault diagnostic data without the need to read meters or gauges. It does not, however, completely satisfy all the functions of fault diagnostics. In addition, it did not provide adequate flexibility that was projected to be needed when the maintenance aids function was to be incorporated.

The display technique utilizing dot matrix gas-discharged message panels is an attractive approach. It can provide for system-to-operator messages, limited quantities of performance trend and status data and is capable of being applied to flight systems having a small size and low power consumption. The display capability (maximum number of characters on display panel) however, is limited. The technique is not satisfactory for applications in experimental systems where a large quantity of display messages are expected during early development stages.

TABLE 2 OPERATOR/SYSTEM INTERFACES AVAILABLE

Visual

- Dials and gauges
- Illuminated transparent switches, symbols, indicators and message displays
- Visible or Dead Face[a] Legend Graphic Annunciator Display
- Four Level Indicator Light Display
- Graphic Display using filmstrips - random access
- Gas Discharge (GD) Matrix Message Panel Display
- Cathode Ray Tube (CRT) Display
  - Black and white
  - Multicolored (e.g., up to 8 colors)
- Graphic or Intelligent Displays - change symbol format and manipulate alphanumeric and graphic symbols under software control (panel form in the library)
  - Graphic using alphanumerics - nonblinking
  - Graphic line generation - blinking, erase
  - Graphic line generation - with multicolors

Contact/Touch Activated

- Standard keyboards
- Custom keyboards
- Light pen interaction with CRT

Audio

- Warning sounds - bells, buzzers, sirens
  - Continuous
  - Beep
- Voice Output systems - stored spoken words

(a) Blank until illuminated.

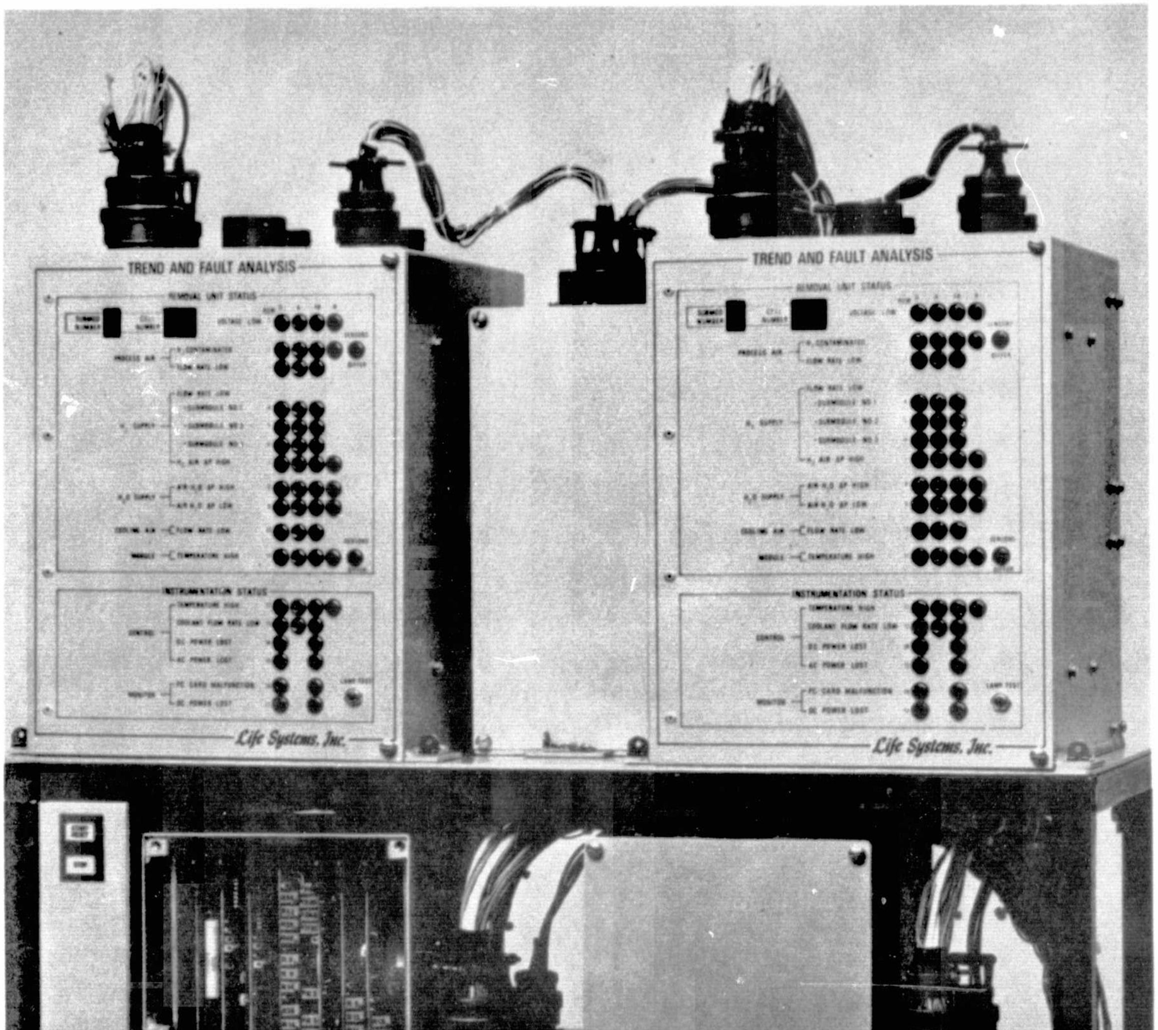

FIGURE 2 FOUR-LEVEL INDICATOR TYPE OPERATOR/SYSTEM INTERFACE

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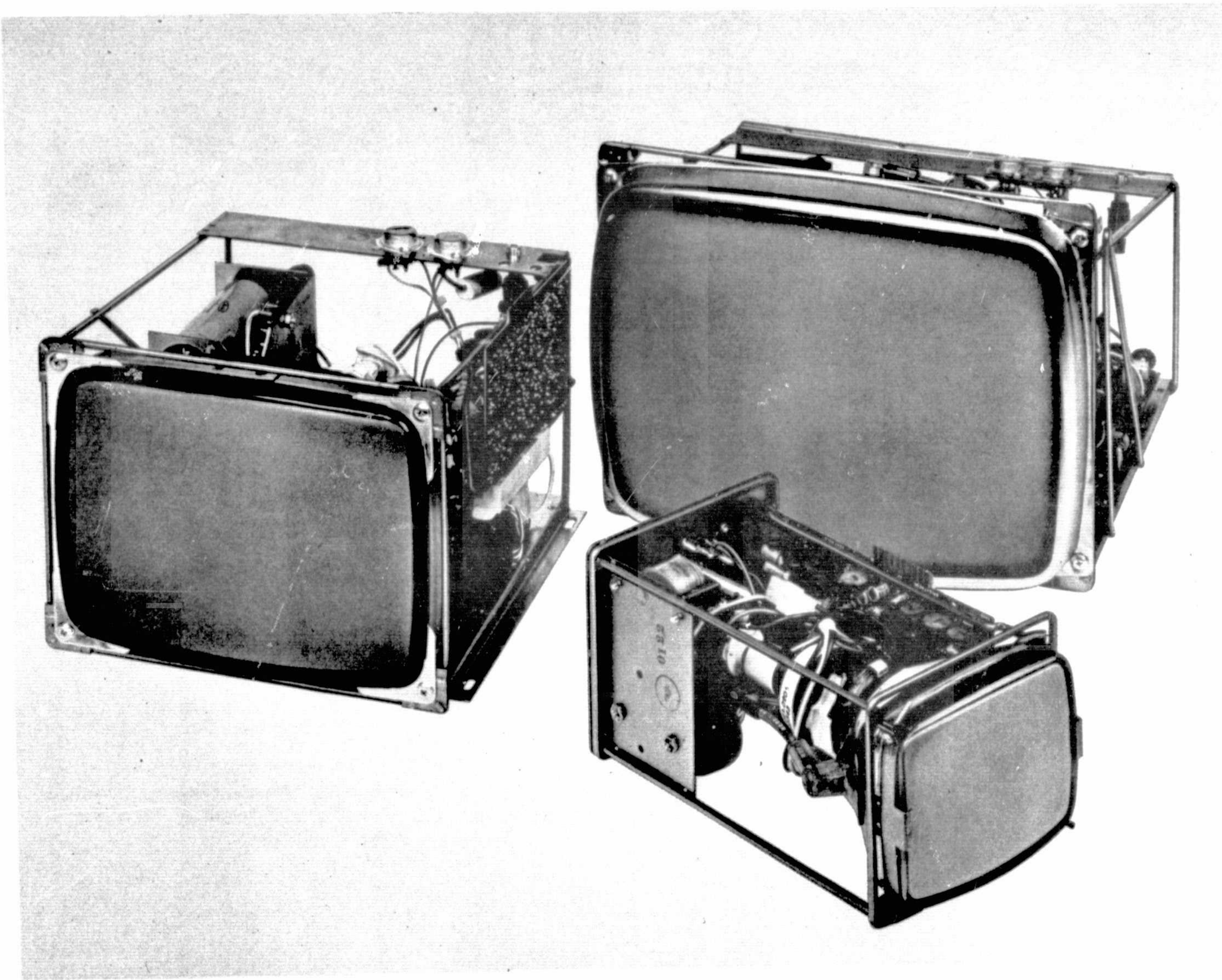

FIGURE 3 CRT DISPLAY UNITS

FIGURE 4 GD DISPLAY UNIT

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The display technique utilizing a CRT is particularly attractive when large quantities of information is being exchanged between an operator and a system and where visual readout of this information is rapidly required.

Table 3 gives a comparison of the CRT and the GD type display characteristics. It shows that the life expectancy, legibility, driving voltage, power consumption, size, weight, maintenance requirements and readability from distance are in favor of the GD type display techniques. On the other hand the cost and data capacity are in favor of the CRT type display technique. The display capability (maximum number of characters on display panel) is usually limited to 480 characters on a GD type display panel as compared to 1,920 characters on a CRT type display panel. The CRT type display panel is therefore overwhelmingly better than the GD type display panel in applications of experimental systems where a large quantity of display messages are expected. The technique utilizing an intelligent graphic display was eliminated because of its large physical size and the required extensive software program. Therefore, it is concluded that the black and white CRT display is optimal for flight experiment instrumentation design within the criteria for size, display capacity and development cost.

GD Display for the Future. The display characteristics shown in Table 3 clearly indicate that the GD type display will ultimately be the display of future EC/LSS instrumentation of which the data display capacity is expected to be lower than that of the present design.

Contact/Touch Activated Interface

Not withstanding that various standard contact/touch activated interfaces are available, the custom-made keyboard design was selected.

A possible standard off-the-shelf keyboard is an American Standard Code for Information Interchange (ASCII) keyboard (see Figure 5). An ASCII keyboard has the advantage of being flexible through the combinations of the standard alphanumerical keys. However, some training is necessary for the operator to become familiar with entering the command and some level of typing skills is required to use the interface. A computer program is required to edit and interpret a large number of operator commands to be entered via an ASCII keyboard. Therefore, the design with standard keyboards is eliminated for EC/LSS instrumentation because of the larger size, the required operator training and the longer operator/system interactive time when entering commands or data.

Light pen interaction with the CRT is an advanced technique which has received more attention in recent years. However, implementation of this technique requires higher hardware cost. A high resolution graphic CRT terminal instead of the low cost alphanumerical CRT terminal is required in addition to the hardware cost to handle the light pen interaction. The physical size of such a hardware system is also larger than that of a custom-made keyboard.

The advantages of designing with a custom-made keyboard include less operator training time required and faster operation actions in entering the commands. Because the operator command keyboard is custom-made to meet the specific

TABLE 3 COMPARISON OF CRT AND GD DISPLAY PANEL

		CRT	GD
1.	Life Expectancy, h	20,000	50,000
2.	Legibility	Characters uniform ±10% except at display boundaries	Distortion free extremely uniform characters
3.	Driving Voltage	High	Medium
4.	Power Consumption	High	Low
5.	Display Format	Dot matrix or solid	Dot matrix
6.	Character Height	Variable; can be small	Normally larger
7.	Cost per Character	Lower	Higher but reducing
8.	Size	Bulky	Compact, flat
9.	Data Capacity	High; commonly 80 x 24 = 1,920 char.	Low to medium; commonly 40 x 12 = 480 char.
10.	Weight	Heavy	Light
11.	Maintenance	Frequent adjustment on focus, centering	Less frequent
12.	Readability from Distance	Poor	Good

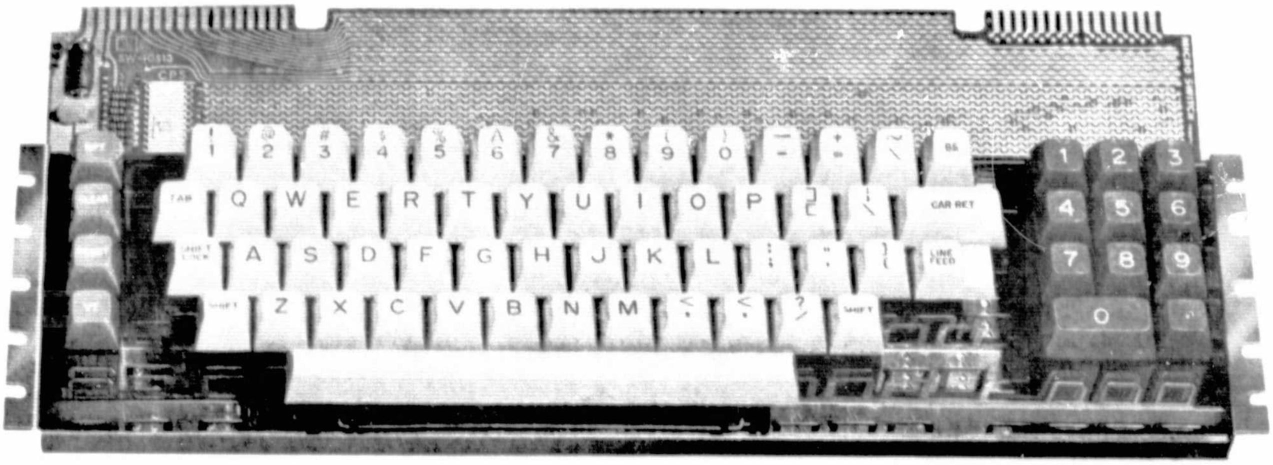


FIGURE 5 OFF-THE-SHELF KEYBOARD

requirements of a subsystem, each of the pushbuttons or keyboard switches is dedicated to a specific function. For example, instead of typing a character string "ON-LINE DISPLAY PRESENT VALUE TEMPERATURE SENSOR 001," the operator can now complete the command by pressing a total of seven pushbuttons: one for type of operation, one for type of function, one for type of sensor/actuator, three for sensor code/data and one to terminate the command strings. Therefore, faster operator action is achieved and less operator training is required. Figure 6 shows the custom-made operator command keyboard for the Experimental One-Person Air Revitalization System (ARX-1) and the Three-Person CO_2 Collection Subsystem (CS-3).

Audio Interface

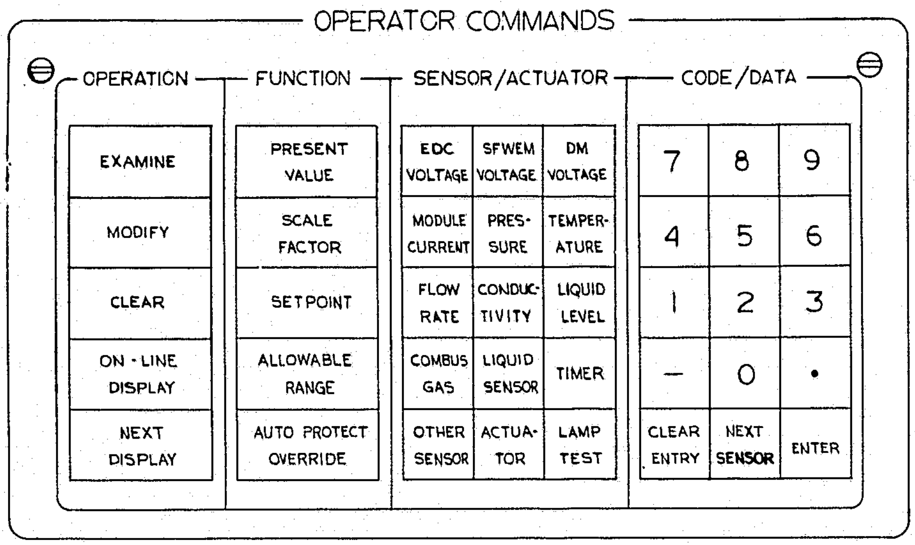
There are two types of audio interfaces: (1) warning sounds such as bells, buzzers and sirens and (2) a more advanced system with voice output. Voice output systems (also termed audio response units) are recent advanced products and are still being developed. Their costs are comparatively high and performance has not yet reached the proper maturity stage. The audio interface selected for the EC/LSS instrumentation is a buzzer design which is used to alert the operator whenever a system alarm shutdown has occurred. The frequency of the buzzer can be controlled by the computer so that different frequencies (number of beeps per second) are available for different conditions. For demonstration, only one level is implemented.

Options for Front Panel Mounted Items

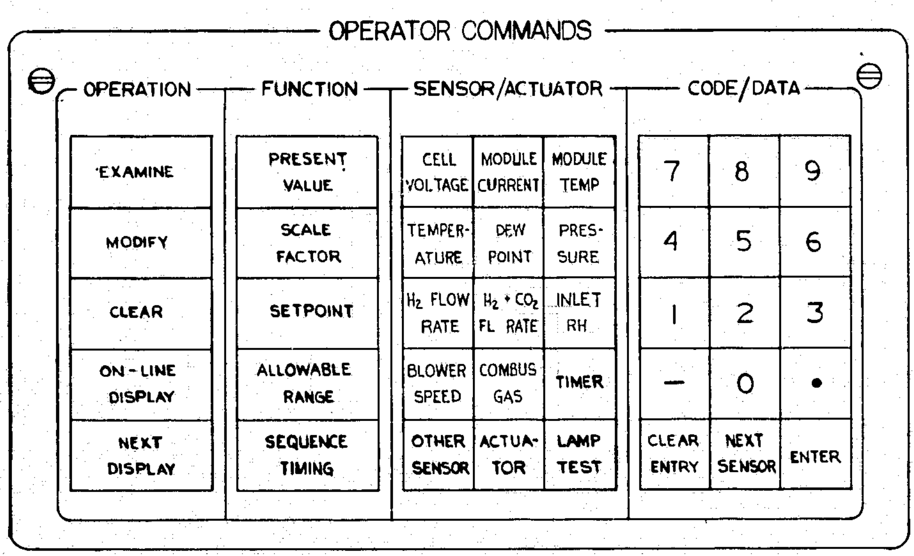
The options for front panel mounted items are shown in Table 4. These items include system power components (circuit breakers and power on/off pushbuttons or switches), control components (override switches, control knobs, control switches, control selection pushbuttons, control mode and transition status display, auxiliary mode selection, concealed or recessed overrides and controls, control command pushbuttons) and monitor components (monitor messages, monitor commands, monitor resets, parametric data displays, test points, valve position indicators, three or four level lights, lamp test buttons, elapsed time indicators, system schematic or simplified schematic combined with status indicators, etc.). An EC/LSS instrumentation designer can choose features from this table to decide what front panel components should be included for a specific requirement.

Human Engineering Design of Operator/System Interface

A general front panel layout illustrating its universal applicability is shown in Figure 7. The right-hand side of the panel consists of the system control functions. It contains the control pushbuttons for manually selecting operating mode/commands. The bottom right-hand side provides for manually overriding the automatic protection and actuators as well as a location of incorporating actuator control adjustment knobs. The control status section provides an operator with an indicator alerting him when the automatic protection is off, when the actuator overrides are on and when the panel switches are disabled so unauthorized personnel cannot change the operation. The left-hand side of the panel contains the system status information. It is divided into three areas:



ARX-1



CS-3

FIGURE 6 ARX-1 AND CS-3 OPERATOR/COMMAND KEYBOARDS

TABLE 4 LIST OF OPTIONS FOR FRONT PANEL MOUNTED ITEMS

- Circuit Breakers
- Power On
- Test Points
- Parametric Data Displays
- Valve Position Indicators/Override
- Multiple Level Lights
- Totally Blank, (Start/Stop Only)
- Remote Locatable
- Lamp Test Buttons
- Elapsed Time Indicators
- Override Switches
- Control Knobs
- Control Mode Selection
- Control Mode Transition Status
- Auxiliary Mode Selection/Status
- Concealed Overrides/Controls/Recessed Panel
- Control Commands
- Monitor Messages
- Monitor Commands
- Monitor Resets

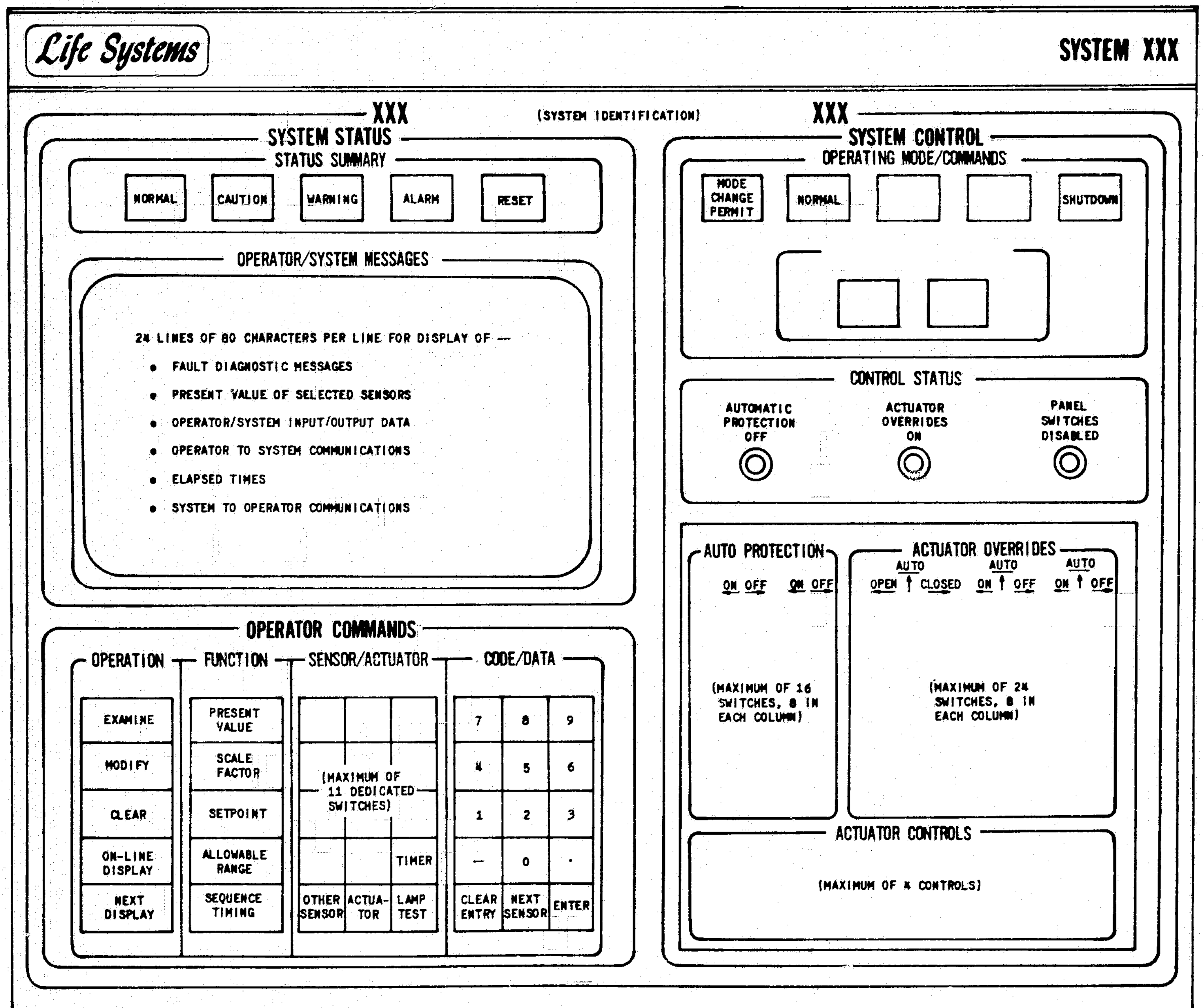


FIGURE 7 UNIVERSAL EC/LSS OPERATOR/SYSTEM INTERFACE PANEL

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system status summary, operator/system messages and operator commands. The system status summary reflects the worst case of the four levels of the performance trend concept: normal, caution, warning and alarm.

The human engineering design features of the above-described instrumentation front panel include the following:

a. The control and monitor instrumentation functions are grouped individually: control on the right-hand side and monitor on the left-hand side.

b. The control functions are further grouped into operating mode/commands, control status, automatic protection overrides, actuator overrides and actuator controls.

c. The monitor functions are further grouped into system status summary, operator/system messages, and operator commands.

d. The operator commands are further grouped into operation, function, sensor/actuator and code/data.

e. A "MODE CHANGE PERMIT" pushbutton is incorporated into the system control pushbuttons so that pressing two buttons simultaneously is required to enter a system control command. This design eliminates any accidental activation of the control buttons.

f. The overrides, switches and control knobs are concealed in a recessed panel to limit access to trained operators only.

g. The operator authorization password concept is incorporated into the design to prevent any unauthorized personnel from changing the system operation.

h. An audio signal is used to alert the operator of a system alarm shutdown.

There are other human engineering considerations in the areas of CRT message display design and maintenance aid instruction design which will be discussed in the latter part of this report.

Operator Commands

One of the benefits of computer-based instrumentation is that the software allows flexibility in changing control and monitor setpoints and characteristics. The available operator commands for the EC/LSS instrumentation are shown in Figure 8. These operator commands include:

1. The basic functions a test engineer would normally need to examine and modify the control and monitor setpoints.

2. The basic functions a test engineer would normally need to carry out a test program such as to examine the present value of an analog sensor and to request the present value of an analog sensor data be displayed and updated constantly among several.

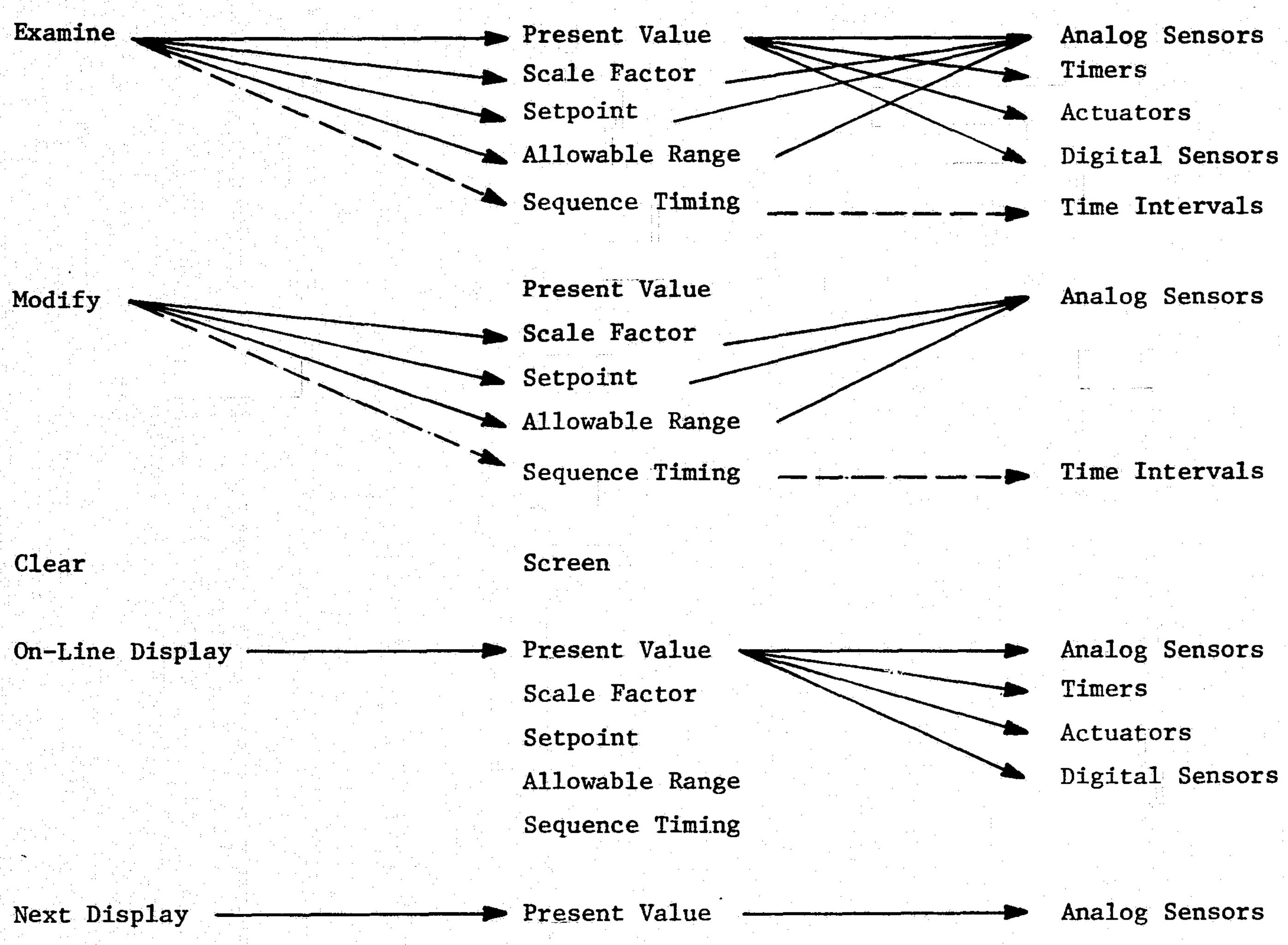


FIGURE 8 OPERATOR COMMANDS AVAILABLE

3. The functions to clear the display screen, to acknowledge system messages and to request (in an interactive manner) that more messages be displayed.

Examine

The "examine" function allows an operator to examine the present value of an analog sensor, a digital sensor, a timer and an actuator status. It also allows the operator to examine the scale factor of an analog sensor, the setpoints of an analog sensor, the allowable range of an analog sensor and any sequence timing constants. The real-time data of the requested parameter will be displayed on the CRT display screen at the time of the examine function. The displayed data are not updated automatically after the completion of the function.

Modify

The "modify" function allows an operator to make modifications to the scale factor of an analog sensor, the setpoints of an analog sensor, the allowable range of an analog sensor and any sequence timing constants.

On-Line Display

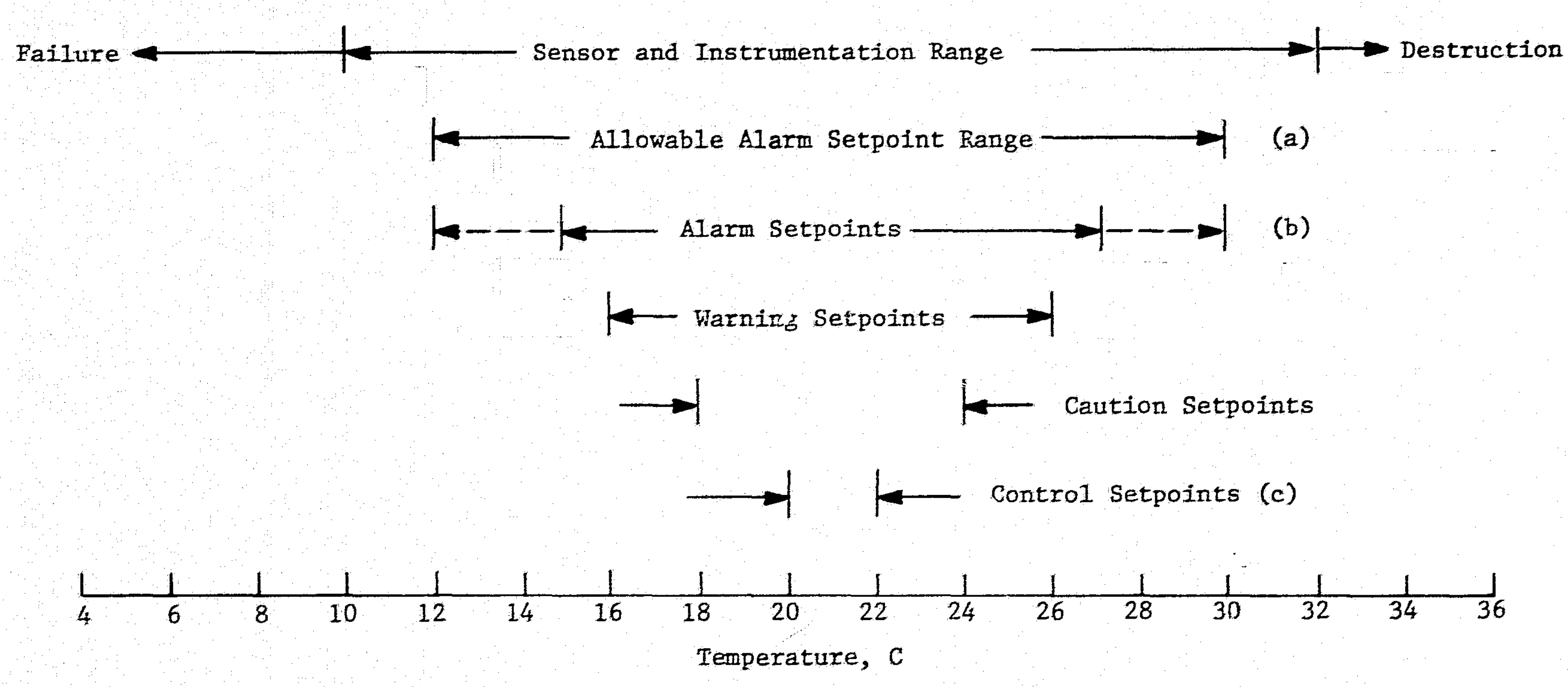
The "on-line display" function allows the operator to request that the present value of a digital actuator, an analog sensor or a timer be displayed on the CRT screen and be updated at a predetermined rate, typically two to several seconds (but could be as long as a few minutes).

Setpoint Modification Relationship

Figure 9 shows the relationship between the setpoints of an analog sensor. This relationship is important for an operator to make correct modifications to control and monitor setpoints. The figure illustrates the relationship with a temperature sensor range. Control setpoints are usually set at the narrowest band; e.g., between 21 and 24 C. The next one in the hierarchy is the caution band; e.g., the temperature caution setpoints may be at 20 and 25 C. Warning setpoints are next in the hierarchy; e.g., 18 and 27 C. Alarm setpoints are next after warning setpoints; e.g., 16 and 29 C. All the setpoints mentioned so far have to maintain their relative hierarchical relationship beginning from the control setpoints to the alarm setpoints. In addition, all these setpoints have to fall in the range of allowable alarm setpoints. This allowable range concept is designed to prevent an operator from mistakenly resetting any of the previously-mentioned setpoints to a level where it may exceed the physical limits or it may create hazards to the system. For example, the allowable range for the temperature sensor mentioned above may be from 10 to 35 C.

Authorization Code

An authorization code concept is incorporated to prevent any unauthorized operation of the control and monitor instrumentation. As shown in Table 5, there are five personnel authorization levels. At the lowest authorization



(a) Software imposed limit on allowable modifications
(b) Maximum flexibility without factory reset
(c) Passwords needed to change setpoints -- different level, different authorization code

FIGURE 9 SETPOINT/OPERATOR MODIFICATION RELATIONSHIP

TABLE 5 AUTHORIZATION CODE LEVELS

Level	Authorization
1	Cannot operate panel switches
2	Cannot modify
3	Can modify - Control setpoints - Normal, Caution and Warning setpoints - Sequence Timing
4	Can modify Alarm setpoint
5	Can modify factory-installed alarm allowable range

level, the person cannot operate front panel switches. At authorization level 2, a person can operate front panel pushbuttons but cannot modify any of the parameters or setpoints. At authorization level 3 a person can operate the front panel and modify the Control Setpoints, Normal, Caution and Warning setpoints and Sequence Timing Constants. At authorization level 4, a person is allowed to modify the Alarm setpoints in addition to those described above. At the highest level, level 5, a person can modify the factory-installed allowable range setpoints and sensor scale factors in addition to all of the above described setpoints.

The authorization code design illustrated above is important when restrictions of access to the system characteristics modifications are desired. However, the levels of authorization code in an actual implementation could vary with systems. For example, a designer may elect to implement only two or three levels of authorization codes.

CRT Display Partition

A number of CRT partition options were evaluated (see Table 6). These options include dedicated communication areas, dedicated fault diagnostic areas, horizontal partition, vertical partition, on-call full screen display, on-call full screen fault diagnostics and real-time data display. Among these options three are evaluated in greater detail. These three options are shown in Figures 10, 11 and 12.

Figure 10 shows a partition of the CRT display into the following areas: fault diagnostic messages, on-line sensor data display, operator command display, operations outputs and data input display and system/operator communication display. The display capacity of each of the partitions mentioned above may vary as long as the total capacity is within 24 lines and 80 characters per line. A typical partition would have six lines for fault diagnostic messages, eight lines for on-line data display, one line for operator command display, eight lines for output and input display and one line for system/operator communication display.

Figure 11 shows a partition of the CRT screen into the following areas: fault diagnostic messages, on-line data display, operations output and data input display, operator command display, timer display and system/operator communication display. Typical capacities of the partitions are eight lines for fault diagnostics messages, eight lines for on-line data display, five lines for output and input display and one line for each of the operator command, timer and system/operator communication displays.

Figure 12 shows a more advanced and ideal partition of the CRT display screen. It utilizes both horizontal and vertical partitions. The screen is divided into the following areas: fault diagnostics up to 24 lines and 40 characters per line, operating station and operations output/data input area up to 21 lines, 60 characters per line, four timers (15 characters per timer), one line of operator-to-system command (60 characters) and one line of system-to-operator communication display (60 characters).

TABLE 6 CRT DISPLAY PARTITION OPTION

Option	Description	Human Factor	Programming Effort	Buffer Memory
1	First-in-first-out (FIFO) mixed full screen display; no partitions, no dedicated areas	Bad	Lowest	1K
2	FIFO, mixed full screen display, reserved one line for communication display	Bad	Low	1K
3	Partition and dedicate areas horizontally for different operations	Good	Medium	1K
4	Same as 3 but allows whole screen for fault diagnostics on request	Good	Medium	2K
5	Same as 3 but allows whole screen for on-line sensor data display on request	Good	Medium	2K
6	Same as 3 but stores more information inside computer (the "mini-pages") for display on request	Good	Medium	2K
7	Partition and dedicate areas vertically for different operations	Good	High	2K
8	Partition both vertically and horizontally	Very Good	High	3K
9	Display system status normally and dedicate whole screen to specific operations upon request	Excellent	Very High	3K

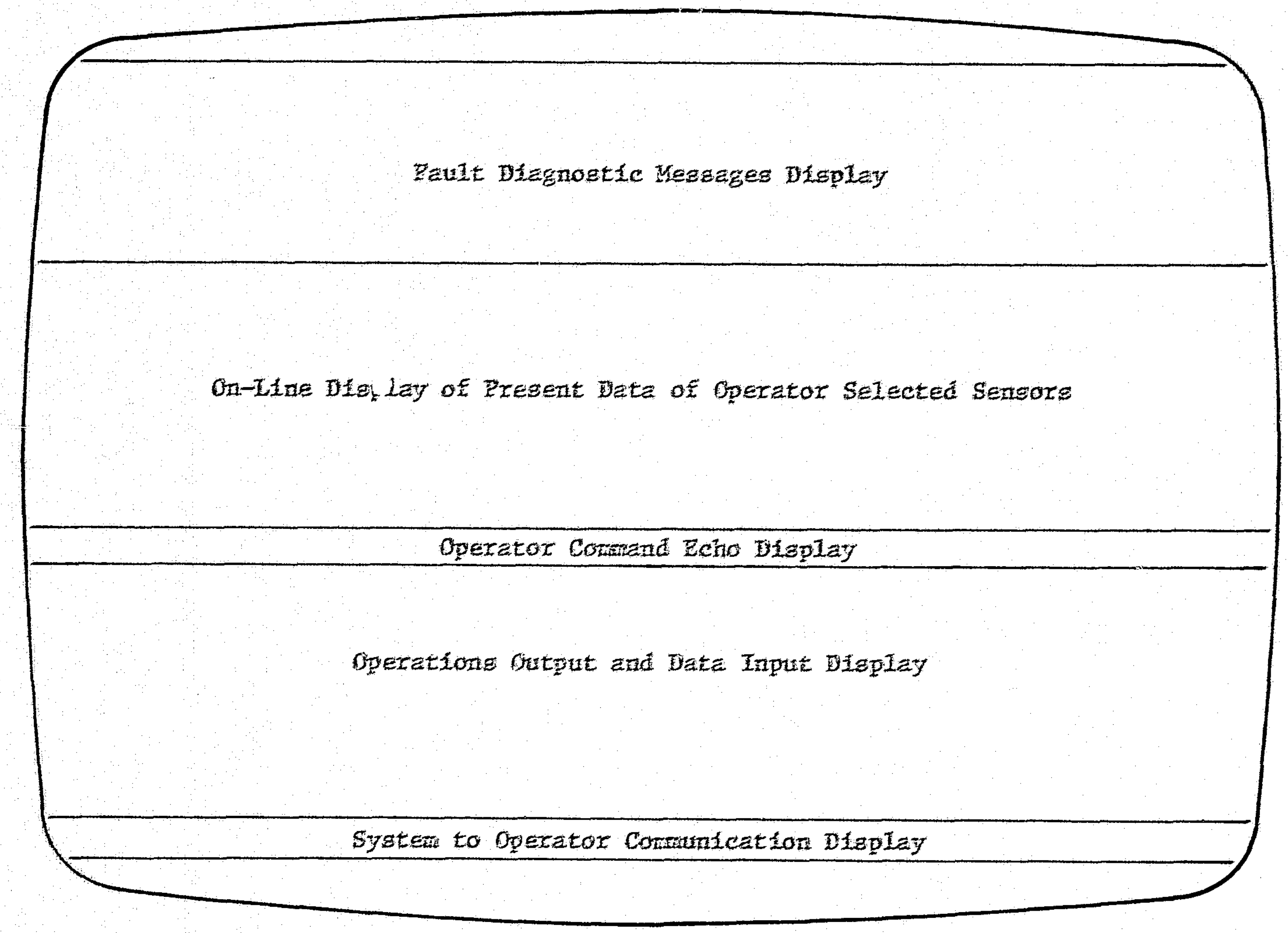


FIGURE 10 CRT DISPLAY OPTION 1

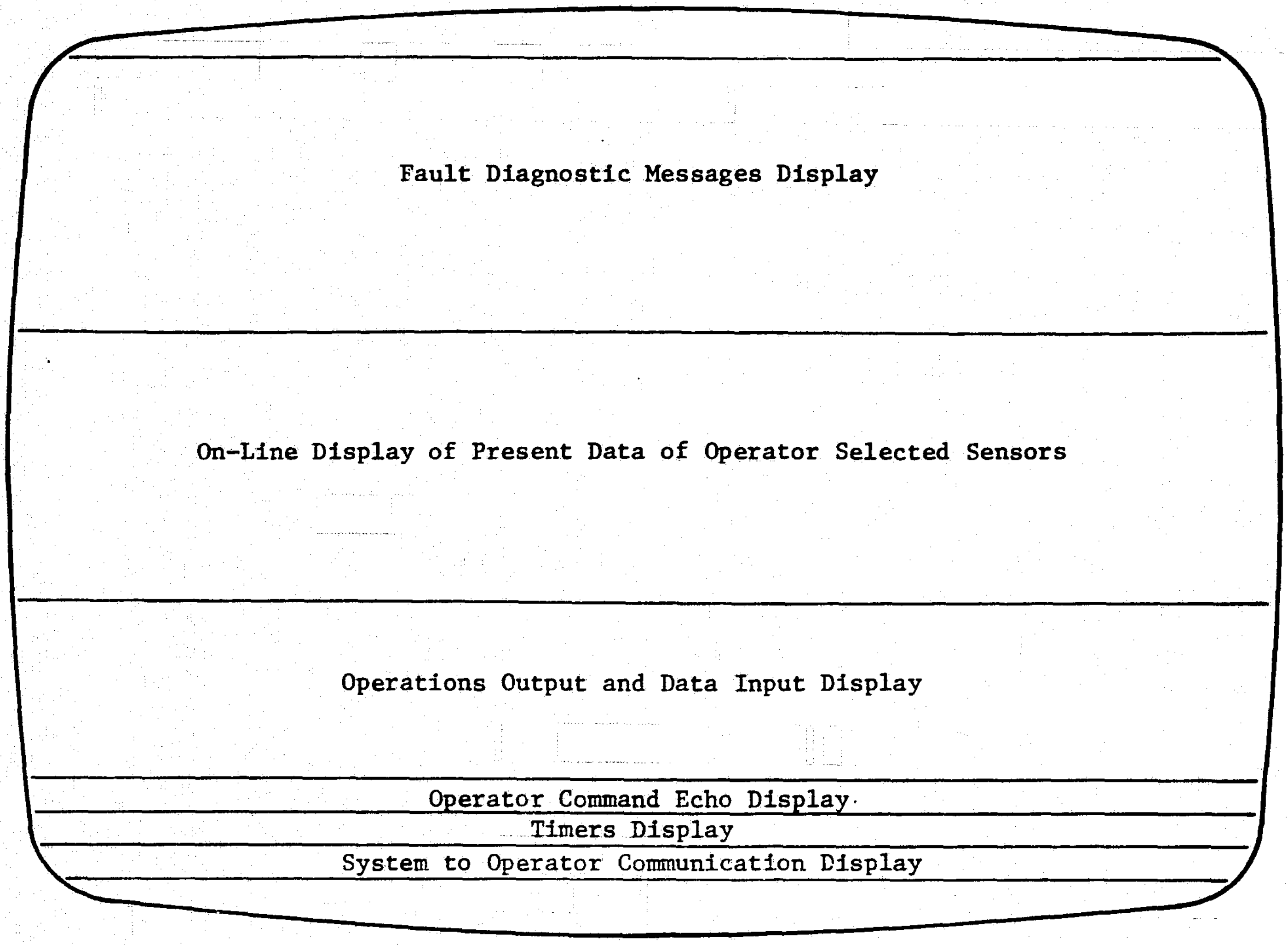


FIGURE 11 CRT DISPLAY OPTION 2

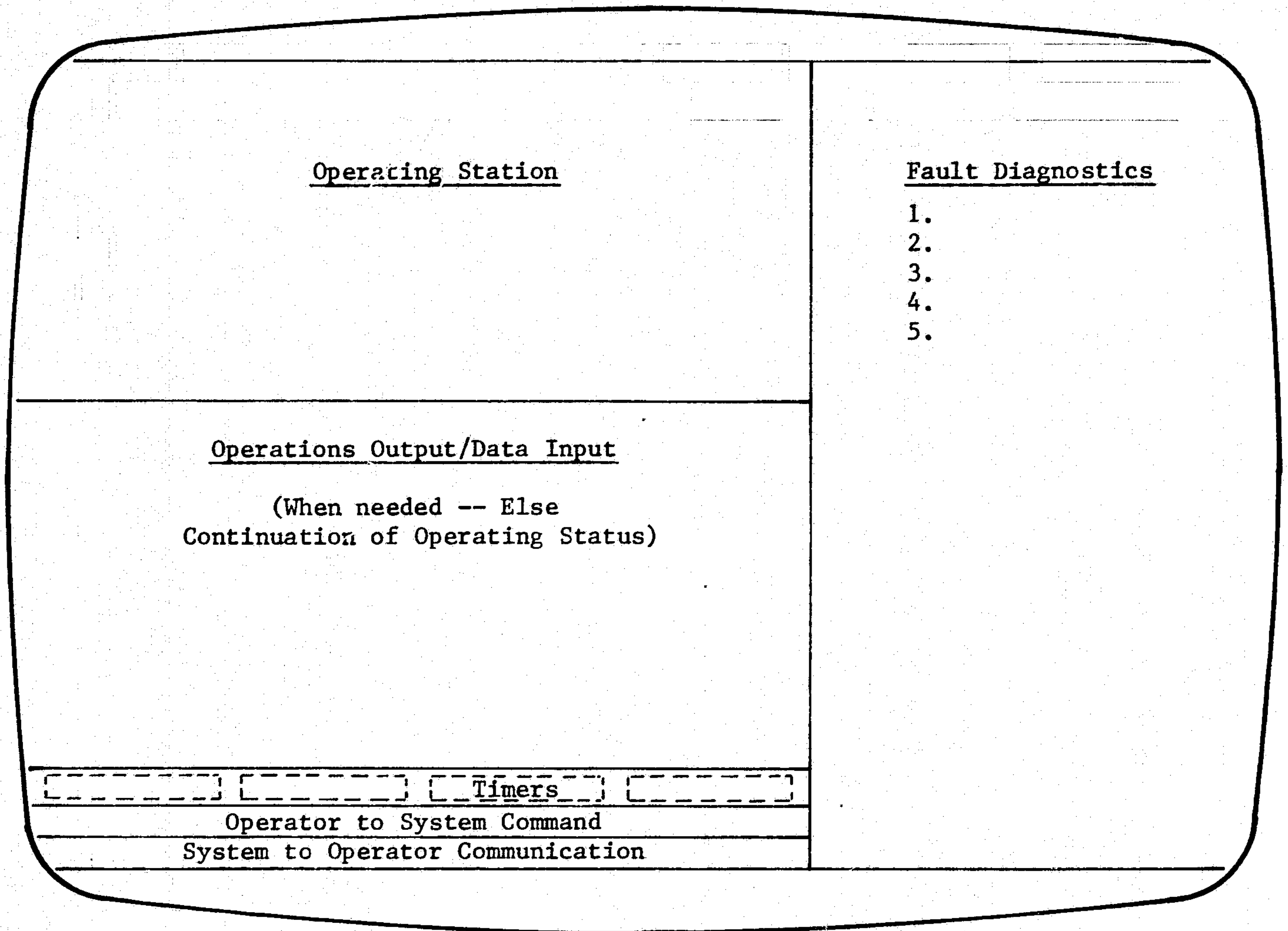


FIGURE 12 CRT DISPLAY OPTION 3

Operator/System Interface Demonstration

Two of the Environmental Control and Life Support Subsystems or Systems under development were selected to demonstrate the operator/system interfacing techniques devised. The two systems are the CS-3 for the Regenerative Life Support Evaluation (RLSE) and the ARX-1. The ARX-1 combines the function of CO_2 removal, O_2 generation, CO_2 reduction, water vapor removal, N_2 generation and water recovery. Both pieces of hardware were developed at Life Systems. Figures 13 and 14 show the front panel design for the ARX-1 and CS-3, respectively.

The operator/system interface is performed solely through the front panel of the systems. Three operator/system interfacing techniques are selected for demonstration: (1) visual, (2) contact/touch activated and (3) audio. For each system the visual interfaces contain a major component, a CRT for alpha-numeric displays. Also, additional visual interfaces are provided through illuminated indicators and pushbuttons. Touch-activated interfaces are included in the form of a customized keyboard as well as pushbuttons, toggle switches and manually adjustable parts. Each system includes, as part of the front panel, an audible warning in the form of a buzzer indicating that a system shutdown has occurred.

Evaluation

The demonstration successfully proved the effectiveness of the operator/system interface. The benefits of the operator/system interface are:

- Reduced operator errors.
- Increased value of testing by having more operating information available in engineering units and in user-oriented instructions.
- Decreased operator time by faster access to data, conditions of system controls, etc.
- Decreased cost of field service by making adjustments available to authorized on-site test engineers.
- Faster system development by more customizing and fine-tuning of system during test programs.
- Decreased development risks because changes can readily be made to setpoints.

MAINTENANCE AIDS

A major requirement of the ARS design is long-term operating life. Such a requirement generally implies failures may occur during the life of ARS operation but the design should provide for quick fault isolation and easy maintenance so that the system can be returned to normal operation once a failure does occur. This is especially important for flight experimental hardware. To avoid extensive crew training and to allow the technically-untrained personnel

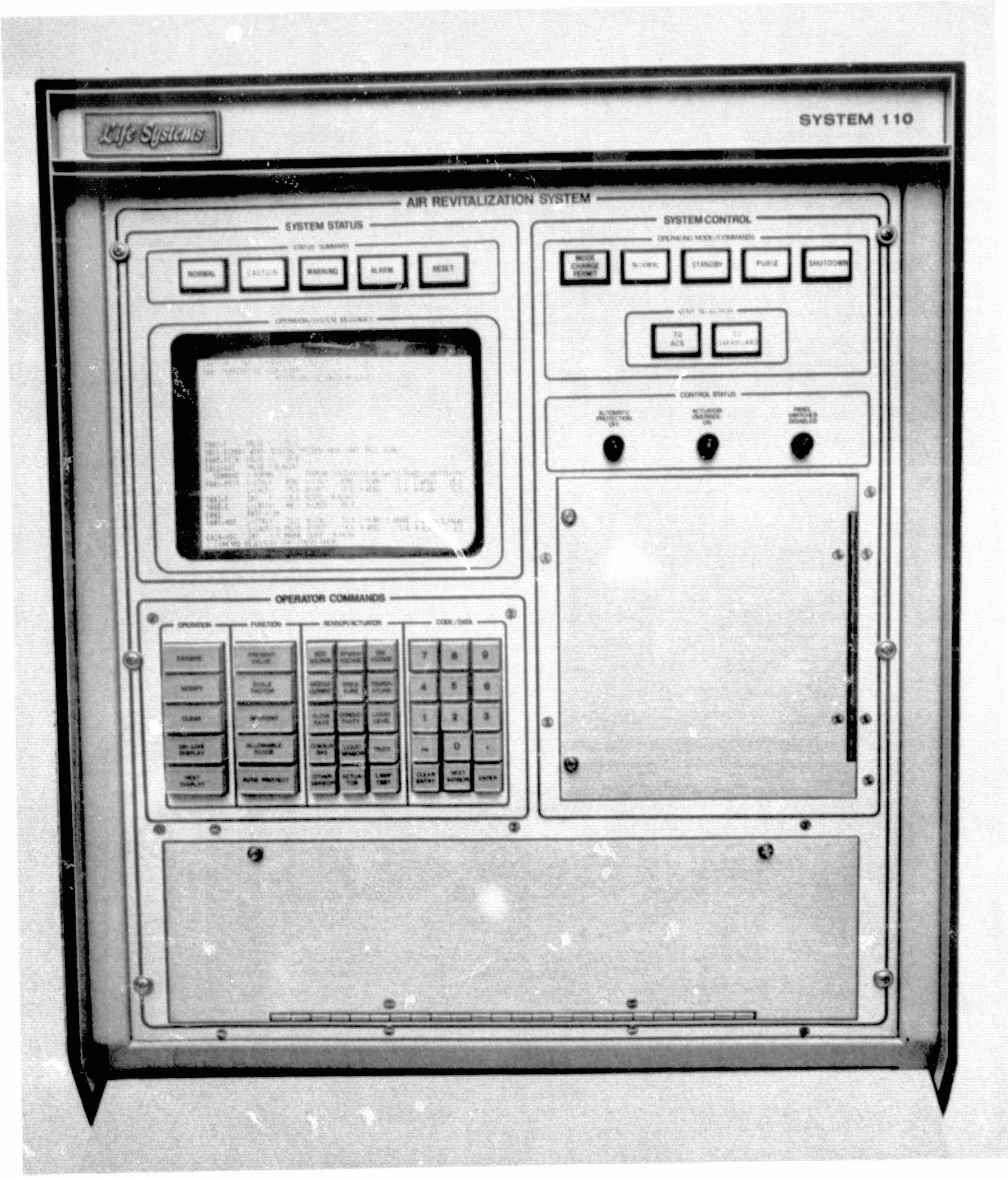


FIGURE 13 ARX-1 OPERATOR/SYSTEM INTERFACE

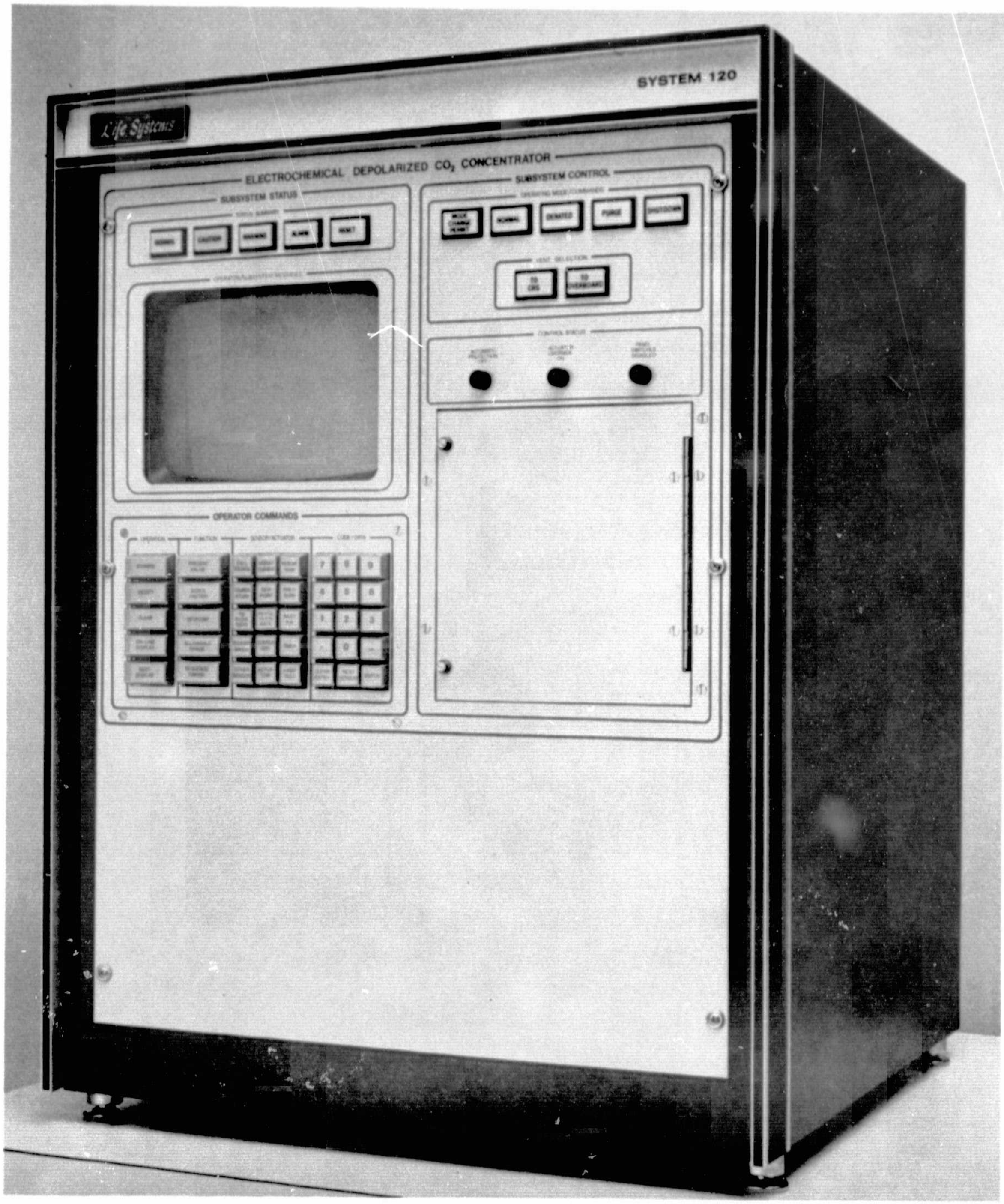


FIGURE 14 CS-3 OPERATOR/SYSTEM INTERFACE

to perform fault isolation and correction, maintenance aids should be provided by the instrumentation which simplify these tasks. This means that all failures must be isolated to the LRU or LRC level by means of the fault diagnostic functions of the instrumentation.

Scope of Fault Diagnostics

Fault diagnostics only include the function of fault detection, fault isolation and fault correction instructions. However, the objectives of the fault diagnostics are to protect the system and personnel and to aid the crew members in correcting a fault with minimum downtime. Therefore, a broader and preferred definition of fault diagnostics is "any functions designed to avoid, predict, detect, isolate or correct a component failure." Before a failure actually occurs the instrumentation should be designed to avoid as many faults as possible and to predict a failure when it has become unavoidable. Therefore, the sequence of fault diagnostics begins with fault avoidance followed by fault prediction as shown in Table 7. When a failure has occurred, the fault detection function next in the sequence should convey to the operator that a failure has happened and then automatically trigger the maintenance aid functions: fault isolation and fault correction instructions. The ultimate goal of the instrumentation is to tolerate failures to a certain extent and maintain the system operation in spite of failures. The fault tolerance function is sometimes referred to as self-healing or self-correcting.

Maintenance Aid Concepts

The maintenance aid scope is summarized in Table 8. The maintenance aid functions start with the completion of fault detection and fault isolation and is completed with the fault corrected. Maintenance aids include the following functions:

- To provide the operator with fault correction instructions to guide and help him in correcting failures.
- To provide self-healing functions which allow the system to continue its operation without external assistance in the presence of failures.
- To provide the operator with scheduled maintenance instructions.

The maintenance aid concepts are further described in the following paragraphs.

Step-by-Step Instructions

In computerized instrumentation, maintenance aids are incorporated into the computer by displaying appropriate maintenance actions step-by-step through the diagnostic and remedial procedures. With computerized maintenance aids the operator does not have to use maintenance reference manuals.

Interactive Information Exchange

The maintenance aid instructions are programmed in an interactive manner. This means that the computer displays a short and precise instruction to the operator. After the action has been taken by the operator he then acknowledges

TABLE 7 SCOPE OF FAULT DIAGNOSTICS

Level	Function	Definition	Example
1	Fault avoidance	Prevent human errors in causing faults	Front panel human engineering, operator authorization codes, scheduled maintenance, etc.
2	Fault prediction	Predict process or components failures by performance trend analysis	Performance trend analysis (normal caution, warning and alarm)
3	Fault detection	Detect symptoms of component failures not necessarily knowing the cause of the symptoms	"Temperature high caution," "pressure low warning," etc.
4	Fault isolation	Triggered by fault detection to isolate causes of a symptom	"Temperature high caused by failure of coolant supply," "blower B1 failed," etc.
5	Fault correction instructions	Instruct the operating personnel on the maintenance actions after a fault is detected	"Pressure too high, check valves V-3 and V-5," "check valve V-1, if normal; then check sensor P2"
6	Fault tolerance	Built-in capability to continue system operation without external assistance in the presence of failures	Triple redundant hydrogen sensors, adaptive control for nonoptimal environmental conditions, etc.

TABLE 8 MAINTENANCE AIDS SCOPE

- Starts with fault isolation[a]
- Completed with fault corrected
- Requires fault correction instructions
  - a. Operator intervention
  - b. Self-correcting

(a) Fault detection has occurred

the completion of the required action. Upon receipt of such an acknowledgement the computer goes on with the maintenance aid instruction, again in a short and precise manner.

Other Maintenance Aid Concepts

As described in the previous section, maintenance aids begin with fault isolation and is completed with fault correction. A narrower but more precise definition of maintenance aids, therefore, only includes fault correction instructions. However, a broader definition of maintenance aids may include any functions designed to minimize the system downtime. These functions include fault prediction (such as the dynamic performance trend analysis) and fault tolerance (such as self correcting) in addition to fault isolation and fault correction instructions. In the following sections, emphasis of maintenance aids will be on the fault correction instruction concepts only.

Types of Failures

Types of failures in an EC/LSS system or subsystems typically include:

1. Mechanical components including actuators.
2. Electronic components including sensors, control and monitor instrumentation.
3. Out-of-specification conditions at the system or subsystems interfaces including power, coolant, etc.

Mechanical Component Failures

Mechanical component failures include the malfunctions of actuators such as valves, blowers, pumps, heaters and electrochemical cells. The failures can be isolated by using the actuator status indicators combined with sensors (both actuator feedback sensors such as speed sensor, regulator position sensors, etc. and parametric sensors such as temperature, pressure and flow). In the EC/LSS subsystems valve position indicators (VPI), regulator position indicators (RPI) and blower speed sensors are designed for fault isolation purposes.

Electronic Component Failures

Electronic component failures include sensor failures and instrumentation component failures. Sensor failures are difficult to isolate except for the cases where dual or triple redundant sensors are used. When dual or triple redundant sensors are used, a miscomparison between two redundant sensor elements indicates that there is a sensor element failure. In the cases where triple redundant sensors are used, when one sensor element fails it can be immediately detected and isolated by the instrumentation voting logic.

To isolate an instrumentation failure and to provide the necessary maintenance instructions, dual redundancy of the instrumentation has to be implemented and built-in checkout instrumentation has to be designed to monitor the instrumentation itself.

System or Subsystem Interface Failures

System or subsystem interface failures include that of the conditions of cooling air, coolant, ambient temperature and ambient relative humidity, shortage or loss of power, etc. Isolation of these failures requires the incorporation of appropriate system parametric sensors.

Line Replaceable Units and Components

It is important to differentiate between LRUs and LRCs with respect to their failures and the ease with which a failure can be located. These differences have been evaluated. In general, failed LRUs are more readily isolated since general systems schematics and configurations are derived by performing fault detection and isolation analysis (FDIA) to the LRU level. The LRCs which form a part of a LRU are more difficult to isolate since provisions must be added to the LRU itself to enable isolation to its LRC level. Very seldom does a mechanical LRU have an LRC. In general, LRCs are reserved for the control and monitor instrumentation of a subsystem. Typical examples are printed circuit cards within the instrumentation that are fault isolatable through built-in-checkout routines.

Maintenance Aids Implementation Options

Table 9 shows the options for implementing maintenance aids (fault correction instructions). Generally speaking, maintenance aids can be accomplished by providing materials which require human interpretation and decision making in the process of troubleshooting or through an automated procedure guided by the computer intelligence.

The manual approaches are those using troubleshooting flow charts and maintenance manuals. The person performing the maintenance requires a considerable amount of knowledge about the system in order to carry out the maintenance task once a failure has occurred and is flagged by the instrumentation. He has to go through the fault isolation procedure specified in the flow charts or manuals which are designed to help him make the decisions. This approach is generally acceptable when specially trained field service technicians are available. To better help the technicians in performing the maintenance, other forms of aids such as microfilmed maintenance instructions can be used. The microfilm approach can reduce a large quantity of maintenance data to a rather small volume which helps the maintenance personnel when travel is required or when storage of maintenance manuals, schematics and flow charts becomes a problem. This approach is particularly attractive to service-oriented organizations since they can dispatch a service person to different customer locations to repair a number of different systems with a small package of microfilm and a microfilm projector. The above-mentioned approaches, however, have the same drawbacks: the requirements for extensive technical personnel training and the large physical sizes of the flow charts, manuals or the microfilm projector.

The tape-recorded type maintenance aids can reduce some amount of training. The recorded messages (either video or audio), when properly done, can serve as on-site instant training. The drawback of this approach is again the technical background needed and the physical size of the recorder.

TABLE 9 MAINTENANCE AIDS IMPLEMENTATION OPTIONS

	Option	Size[a]	Cost	Performance[b]
A.	Manual Maintenance Aids			
	1. Troubleshooting Flow Charts	small	lowest	poor
	2. Maintenance Manual	medium	lowest	poor
	3. Microfilmed Maintenance Instructions	large	low to moderate	poor
	4. Tape-recorded Maintenance Instructions	large	moderate to high	poor
B.	Computer-Guided Maintenance Aids			
	1. Graphic Display of Schematics	largest	high	fair
	2. Interactive Graphic Display of Schematics	largest	highest	excellent
	3. Off-line Interactive Maintenance Instructions	largest[c]	moderate	fair
	4. On-line Interactive Maintenance Instructions	largest[c]	high	good
	5. Built-in Interactive Maintenance Instructions	smallest[d]	high	good

(a) Size: Volume and Weight
(b) Performance Criteria: Human factor, training required, background required and human decision required
(c) If a data acquisition system already exists as a TSA, then the size requirement is minimal
(d) Built into Control/Monitor Instrumentation enclosure

For EC/LSS applications, none of the manual maintenance aids mentioned above is adequate because of the unique requirements of the EC/LSS. These requirements include: (1) the design should be for users who have no electronics background and (2) the system downtime should be minimized. These requirements imply that human decisions in the process of troubleshooting should be minimal and limited to simple step-by-step and "yes and no" type decisions. Therefore, the computer-guided maintenance aids are a must for an EC/LSS application.

Computer-guided maintenance aids can be further divided into those using graphic display terminals, graphic display terminals with light pens, off-line interactive maintenance instructions and on-line interactive maintenance instructions. By using graphic display techniques, detailed system schematics as well as graphic presentation of maintenance (e.g. location of components) can be prepared to aid a technically-untrained person to correct a fault. The operator/machine interaction can be done through the use of a light pen or a keyboard to acknowledge the operator's action during a troubleshooting procedure. This approach, with the computer guidance and the display power of a graphic terminal, eliminates the drawbacks of the manual approaches discussed previously. However, the volume, weight and cost of this approach make it impractical for the EC/LSS hardware. The recommended approach for the EC/LSS maintenance aids implementation is to use computer guidance displayed on an alphanumerical display unit. The display unit could be a CRT/keyboard terminal or the built-in operator/system interface designed for EC/LSS and described in the previous section. The configuration options of computer-guided maintenance aid instructions are:

1. Off-line stand-alone system -- Use a stand-alone computer system with a CRT/keyboard terminal and a floppy disk subsystem (or any magnetic mass storage unit).

2. On-line system with separate computer -- Use a computer system similar to the one described above but with a communication link by which parametric data and status can be transmitted from the control and monitor instrumentation (C/M I) to the "Maintenance Aids" computer.

3. On-line built-in system -- Use the C/M I computer to implement maintenance aids.

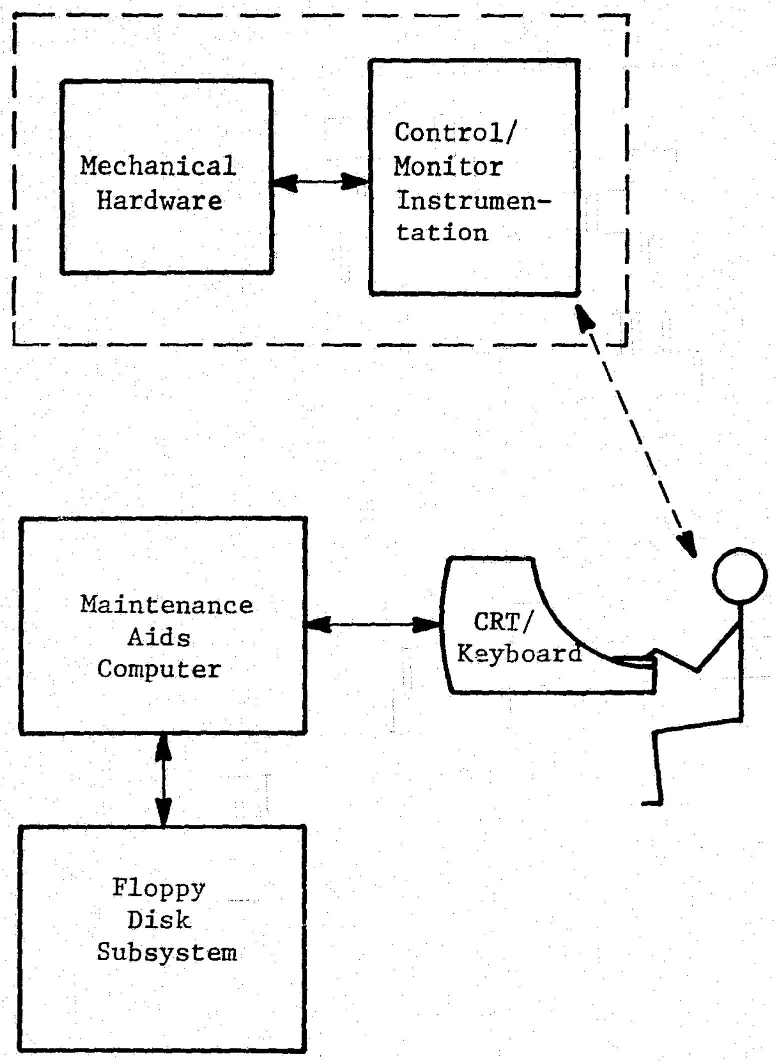
These three options are illustrated in Figures 15, 16 and 17.

The first two options listed above require the use of a dedicated maintenance aid computer which is not a part of the C/M I. The third option can be implemented only if the C/M I is a computerized instrumentation.

In the first option, off-line computer-guided interactive maintenance aids, the fault correction procedure requires extensive human inputs. The operator has to answer questions such as "What is the symptom?," "What is the process air flow rate?," "Does valve V5 position indicator indicate open?" and "Is temperature normal?" Thus, a considerable amount of human inputs and decisions are still needed. Some of the inputs and decisions may be available from the C/M I if the C/M I is designed properly. However, being an off-line system, it still requires the operator to transfer the data or status from the C/M I to the stand-alone maintenance aids computer.

Computer

- Query for symptom
- Provide fault isolation logic
- Provide fault correction logic
- Ask system parametric data or status
- Ask logical questions
- Provide fault correction instructions



Operator

- Enter symptom
- Answer "yes or no" questions
- Enter parametric data or status
- Take correction actions instructed by computer

FIGURE 15 OFF-LINE COMPUTER-GUIDED INTERACTIVE MAINTENANCE AIDS

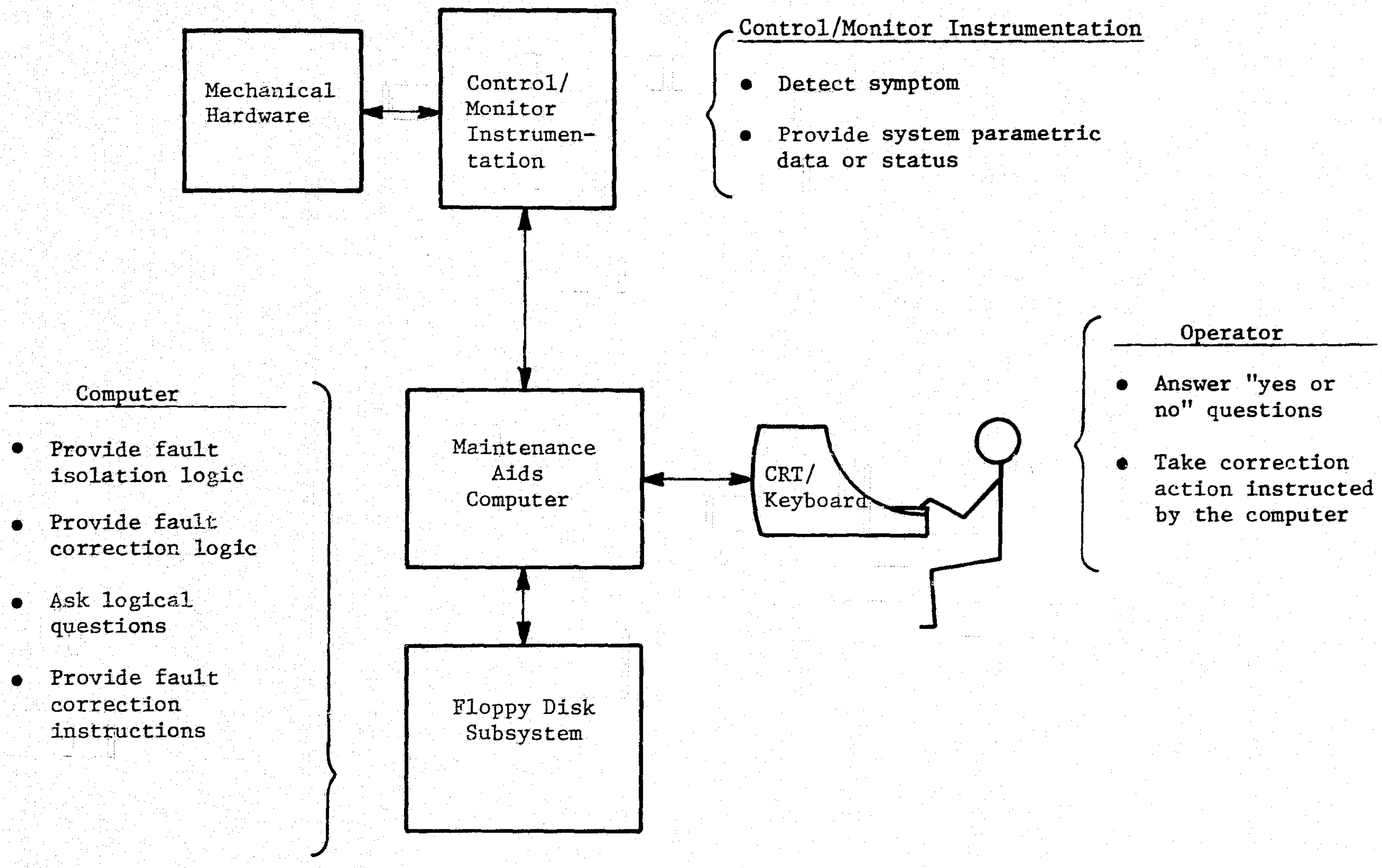
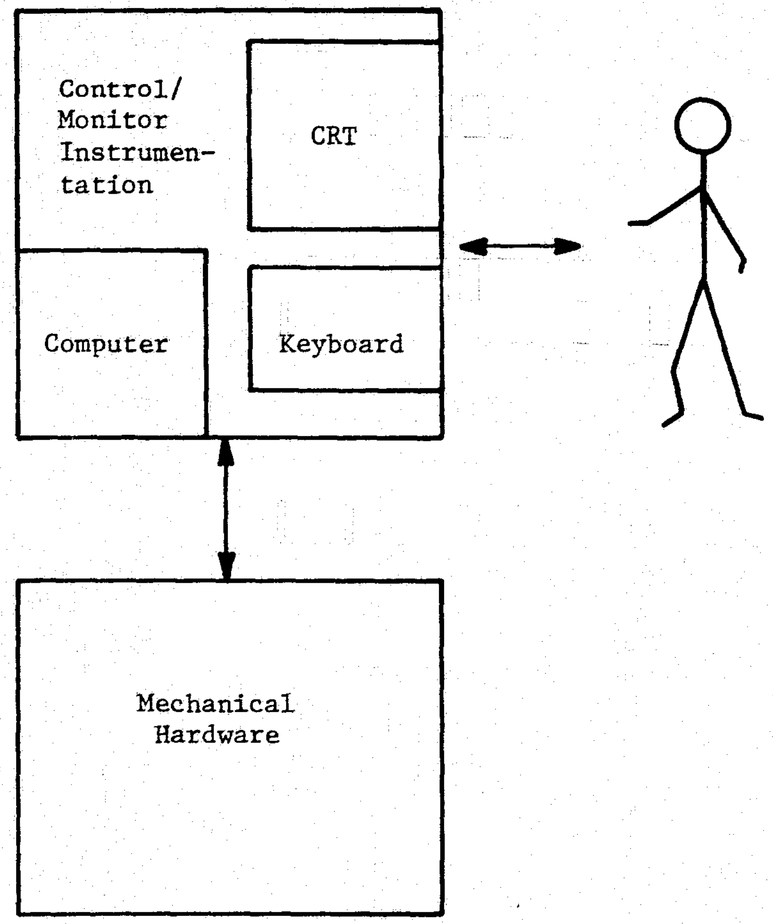


FIGURE 16 ON-LINE COMPUTER-GUIDED INTERACTIVE MAINTENANCE AIDS THROUGH DATA ACQUISITION AND MAINTENANCE AIDS COMPUTER

Control/Monitor Instrumentation

- Detect symptom
- Provide fault isolation logic
- Provide fault correction logic
- Collect system parapetric data or status automatically
- Ask logical questions
- Provide fault correction instructions



Operator

- Answer "yes or no" questions
- Take correction actions instructed by the Control/Monitor Instrumentation

FIGURE 17 ON-LINE BUILT-IN COMPUTER-GUIDED INTERACTIVE MAINTENANCE AIDS

In the second option, on-line computer-guided interactive maintenance aids, the human decision-making portion of the procedure is replaced by the data link between the computer and the C/M I (which also could but not necessarily have a computer in it). The type of questions the operator answers are simpler than those described previously because all parametric data or status are automatically transmitted from the C/M I to the maintenance aids computer for fault isolation analysis and fault correction instruction generation. Short and precise instructions are given by the computer. For example, "check air filter and replace if necessary," "check valve V1, if open enter 1" or "replace V1 driver."

The two approaches discussed above are recommended when detailed, user-oriented instructions are desired. In this case, a large amount of memory is required to store the fault isolation, correction logic and the instructions. This approach is especially attractive if a TSA computer for data acquisition already exists--thus, very little additional hardware cost is involved.

The ultimate goal of maintenance aids is the third approach: built-in computer-guided interactive maintenance aids. This is the case where the fault isolation analysis, the fault correction logic and the correction instructions are programmed into the C/M I software and uses the operator/system interface described in the previous section. This approach provides the C/M I with built-in maintenance aids capability. The degree of maintenance aids and the extent of the instructions depend on the phase of a development program. As discussed previously in this report, debugging effort, flexibility, scientific data, development information and the amount of information exchange through the operator/system interface decrease as the development stage of the instrumentation moves toward production. At the same time, reliability, in situ calibration and fault tolerance needs increase. The increasing amount or degree of reliability, in situ calibration and fault tolerance will eventually relieve the requirements of extensive maintenance aids or interactive fault correction instructions.

Maintenance Aids Demonstration

The maintenance aids demonstration includes the implementation of computer software to predict failures of CS-3 cell voltage, temperature and process air relative humidity and to isolate and correct causes of low cell voltage and low process air flow rate.

Dynamic Performance Trend Analysis Demonstration

Although fault prediction does not fall within the boundaries of maintenance aids, it can help reduce system failures by alerting the operator before a failure actually occurs. Fault prediction is, therefore, important in reducing the amount of maintenance effort.

The dynamic performance trend analysis is a technique to predict a failure by calculating first derivatives of system parametric data. The concept is illustrated in Figure 18. Fluctuations of a sensor reading within the normal limits are typically ignored. Its future projection will be forecasted based on calculated slopes and the "trend" recognized after four consecutive and consistent estimates are encountered.

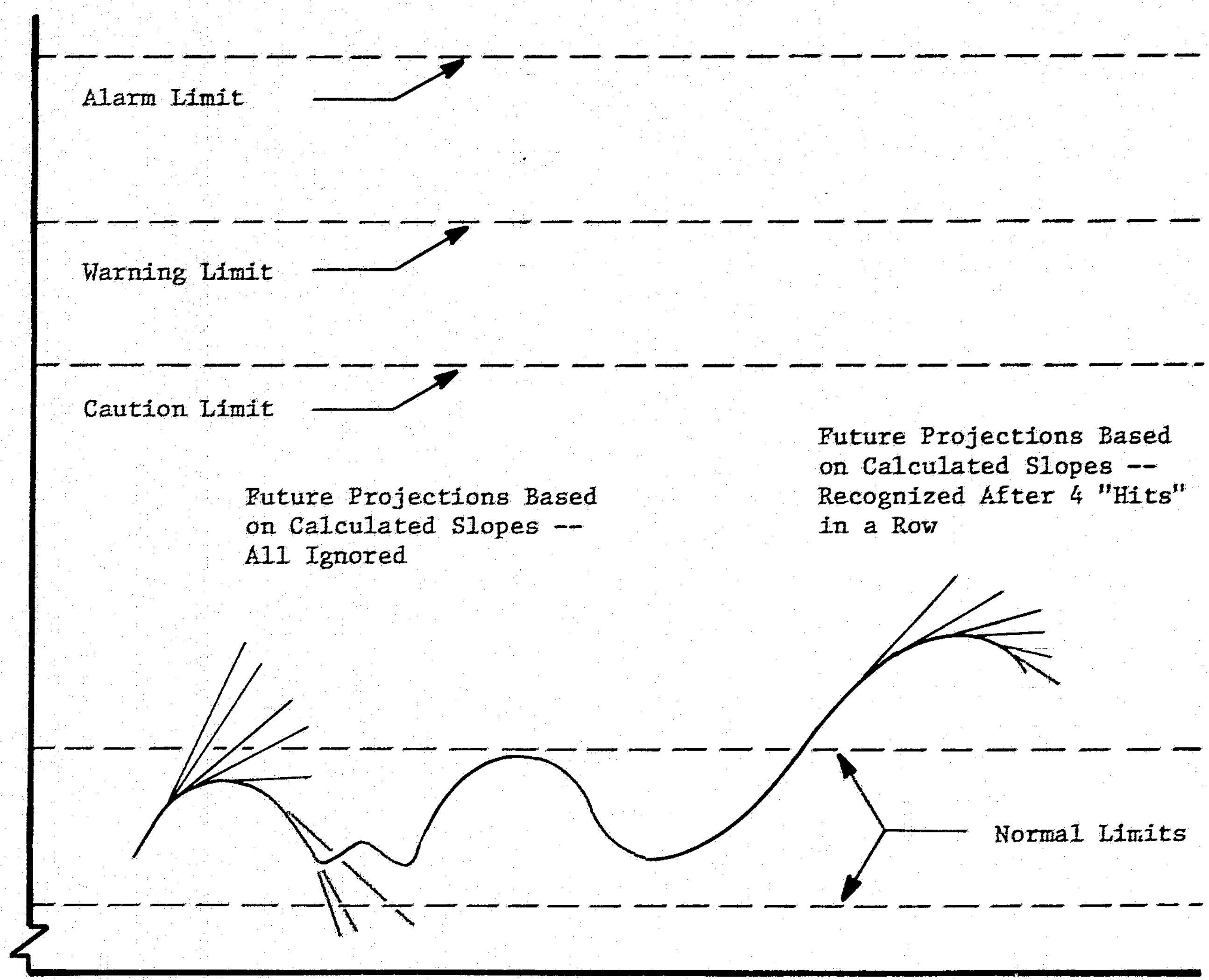


FIGURE 18 DYNAMIC PERFORMANCE TREND ANALYSIS

A demonstration of dynamic performance trend analysis has been implemented within the CS-3 instrumentation. The parameters chosen for this demonstration were cell voltage, module temperature and process air relative humidity.

Fault Correction Instruction Demonstration

A demonstration of fault correction instruction is implemented within the CS-3 instrumentation. The demonstration is designed to isolate the failure which causes low process air flow and low cell voltage. Figures 19 and 20 illustrate how the fault correction instructions are generated for the diagnosis of low process air flow and low cell voltage, respectively.

EC/LSS INSTRUMENTATION TREND

The EC/LSS instrumentation development objectives are directed toward increasing instrumentation capabilities and simultaneously reducing the instrumentation packaging size. The development effort so far, however, is concentrated on increasing the instrumentation capability. Figure 21 depicts the instrumentation evolution from the One-Man Experimental CO_2 Concentrator (CX-1) in the early 1970's, the CS-3 of the on-going program, the next generation ARS instrumentation and the final flight hardware instrumentation.

The significant instrumentation development effort between the CX-1 style instrumentation and the CS-3 style instrumentation includes the development of the instrumentation's architecture using computer-based components, the development of the operator/system interface and maintenance aids as addressed by the current program. From the present instrumentation to the next generation ARS instrumentation requires the following significant effort:

1. Upgrading of the instrumentation's architecture after the completion of the development of operator/system interface and maintenance aids.

2. Incorporation of advanced instrumentation concepts such as the fault tolerance capability, advanced digital control algorithms, built-in-checkout capability and dual redundant processor concepts.

3. Development of next generation instrumentation packaging using state-of-the-art electronics components.

Since this development program started two years ago, significant and tangible electronic advances have occurred which include the following:

1. New microprocessor and microcomputer chips--more powerful microprocessor chips including 16-bit microprocessors and complete microcomputers on a single chip are now available off-the-shelf.

2. Computer memory technologies--larger capacity of Read-Only Memory (ROM) and Random-Access Memory (RAM) are now available off-the-shelf.

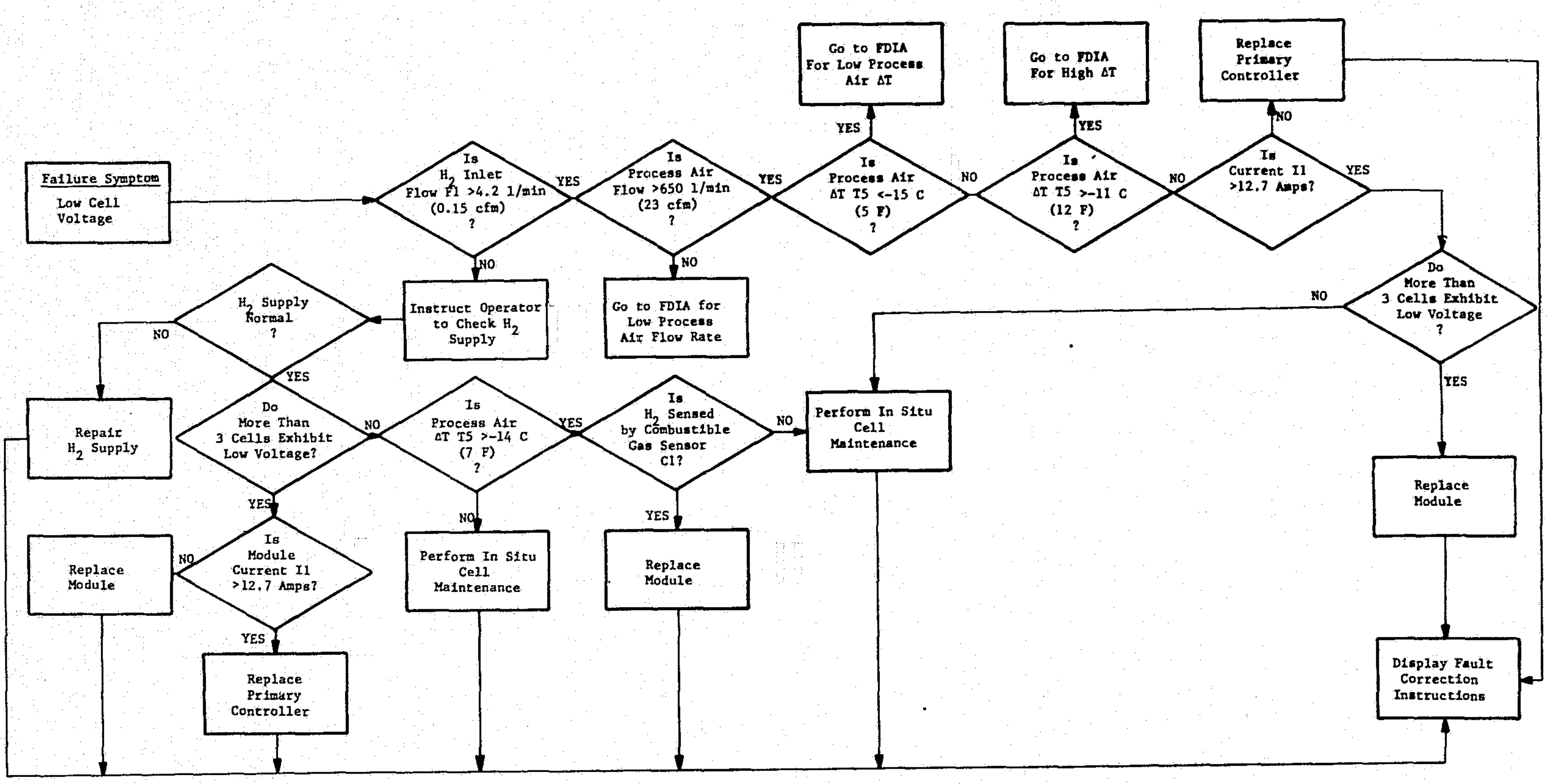


FIGURE 19 CS-3 LOW CELL VOLTAGE FAULT ISOLATION LOGIC

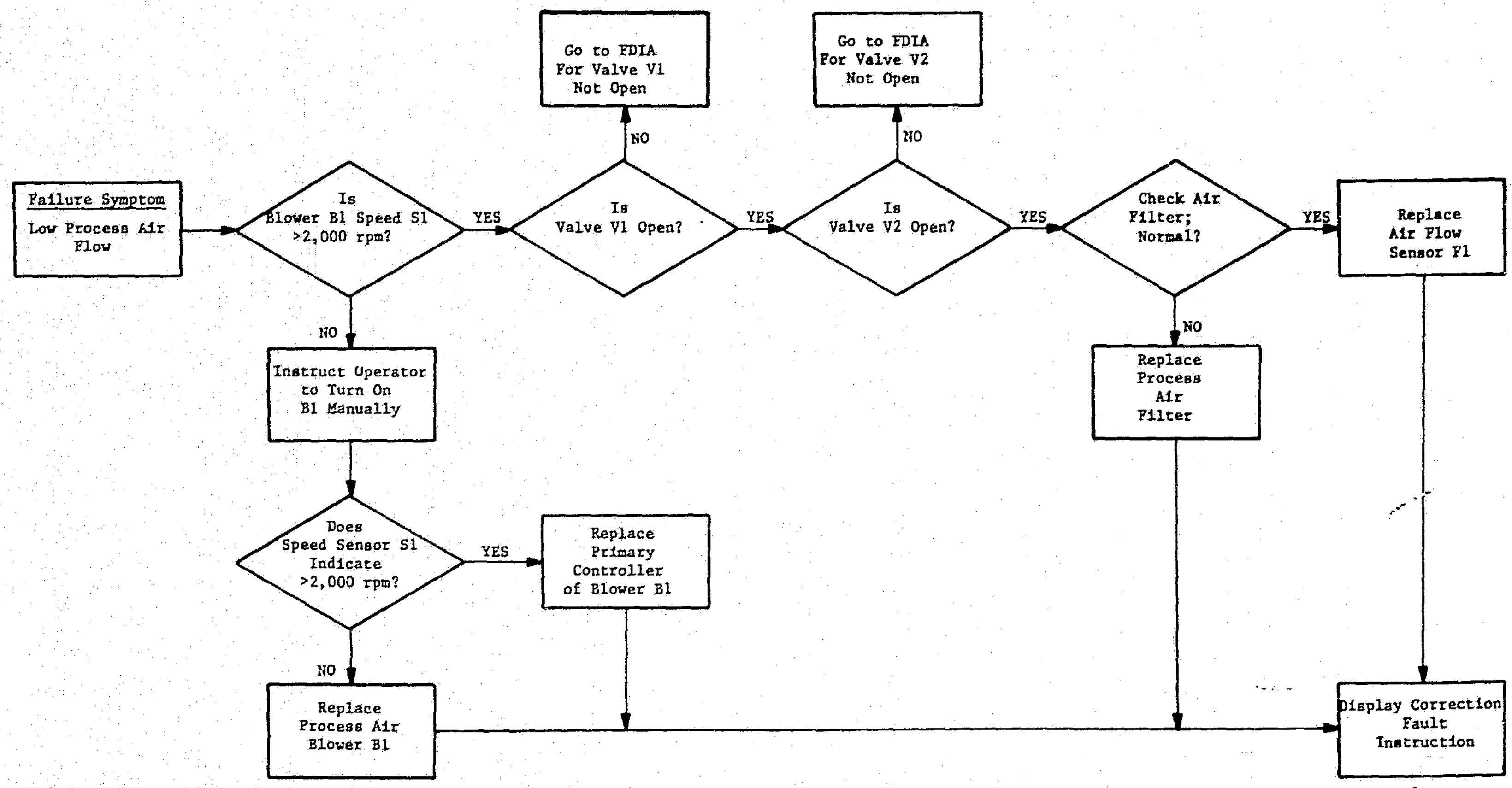
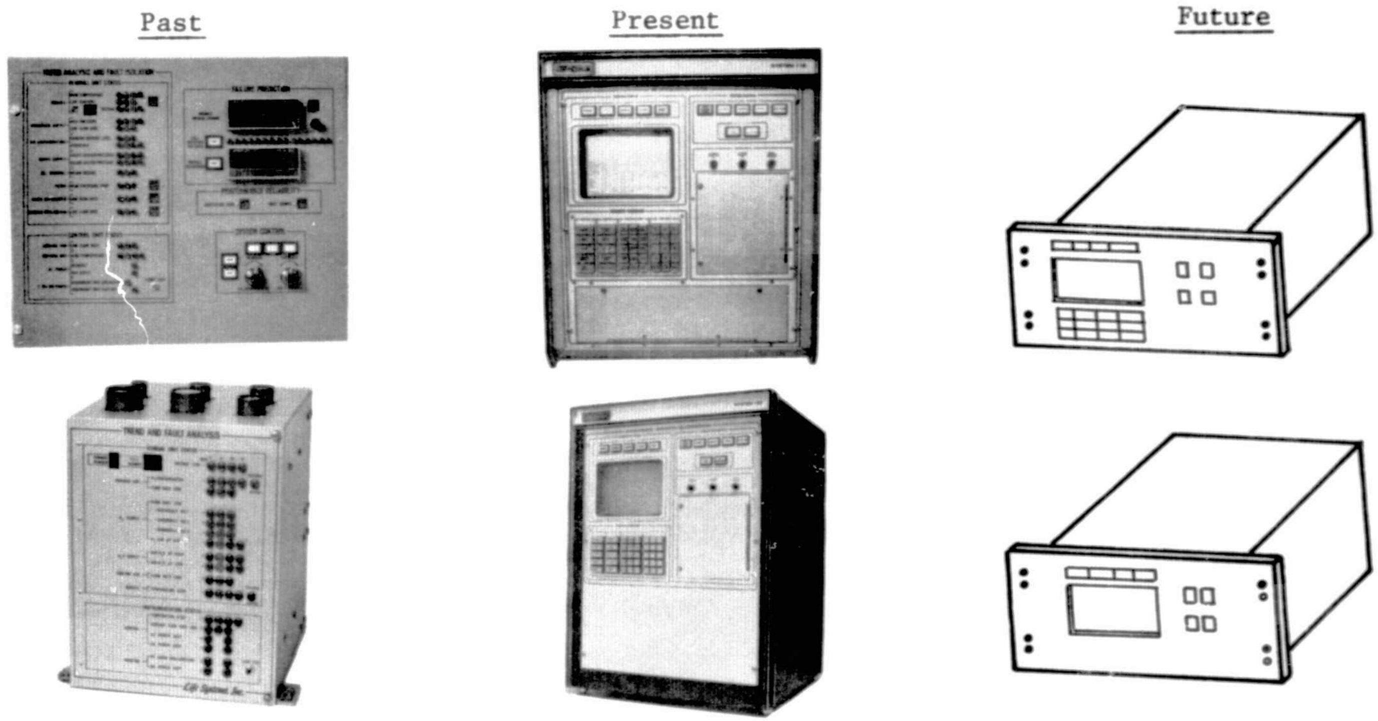


FIGURE 20 CS-3 PROCESS AIR FLOW RATE FAULT ISOLATION LOGIC



Past

- Hardwired
- Four-level indicator
- Adjustment potentiometers/switches
- Limited fault avoidance/prediction
- Fault detection
- Built-in-checkout

Present

- Minicomputer-based
- CRT display
- Advanced operator command keyboard
- Fault avoidance/prediction
- Fault detection
- Maintenance aids (fault isolation, correction instruction)

Future

- Microprocessor-based
- GD display
- Advanced operator command keyboard
- Fault avoidance/prediction
- Fault detection
- Maintenance aids
- Fault tolerance
- Built-in-checkout
- Advanced control techniques
- Smaller size

FIGURE 21 TREND OF EC/LSS INSTRUMENTATION

3. New interface integrated circuits--display controller chips, input/output interface chips, etc. are now available off-the-shelf.

With these newly available electronic components, the size of the EC/LSS instrumentation as demonstrated in this program can be further reduced and the reliability be further increased. It is also anticipated that a final version of the EC/LSS instrumentation may have a remotely located panel or an interface designed to communicate with the spacecraft's central computer. With the advances of electronic technology, these objectives can be met in the near future.

Relatively less effort in the past has been directed toward designing the EC/LSS instrumentation with advanced control techniques. This is partially because the computer-based controller was not available until recently. The digital computer process control techniques have developed rapidly in recent years. The hardware limitations have, for the most part, been solved. Control algorithms from the simple ones such as bang-bang control, proportional-integration-derivative control to the more complicated cascade control, adaptive control, on-line tuning and dead-time compensation techniques should be evaluated and designed for the control of ARS hardware.

It can be predicted that the final version of the EC/LSS instrumentation at the time of actual spacecraft application will be one which communicates with the spacecraft central computer, utilizes the most advanced control techniques for accurate, precise, stable and optimal process controls, tolerates component failures partially or fully, has dual redundant processors and built-in-checkout capability, and displays maintenance aid instructions if failures exceed the fault tolerance capability. It would be designed with a 16-bit microprocessor, Large-Scale Integration electronics, redundant sensor element, low power consumption and small size.

CONCLUSIONS

The goals of this development program include the study, design and demonstrations of operator/system interface techniques and maintenance aid concepts. The results are part of a program to develop advanced instrumentation applicable to an EC/LSS or its subsystems. These goals were successfully achieved and the following conclusions resulted from this development program:

1. The operator/system interface has been successfully designed, checked out and demonstrated with an EC/LSS subsystem (CS-3) and a system (ARX-1). The design proves to have the following benefits:

    - Developments can be carried out with flexibility in modifying operating characteristics such as setpoints, timing constants and calibration curves.

    - Flight hardware or experiments can be carried out with improved efficiency because of the built-in capabilities for displaying parametric data and examining system parameters.

- Human errors are greatly reduced because of the human engineered design and the operator authorization code concept incorporated into the operator/system interface.

2. The operator/system interface design in this development program allows future upgrading using better components that will become available with the advances of electronics technology.

3. Maintenance aid concepts have been studied, evaluated and demonstrated with a subsystem (CS-3). A number of maintenance aid implementation options have been investigated and illustrated. Depending on development stages of a subsystem, maintenance aids can be incorporated into a TSA computer or built into the C/M I itself.

RECOMMENDATIONS

The following additional tasks have been identified and are recommended for future development. The tasks are:

1. Study and incorporate the concept of "self-healing" or fault tolerance. This is the capability to detect and bypass faults within the instrumentation itself with a goal of providing two years of maintenance-free service. Achievement of this capability requires employing a combination of such existing techniques as:

   a. Data/information transmission error checking
   b. Triple modular redundancy
   c. Dual instrumentation operations

2. Evaluate built-in checkout circuits which can verify the integrity of the instrumentation itself and allow maintenance to the LRC level. This activity ties in closely with the detection step of the self-healing concept listed above.

3. Investigate the concept of using initial actuator "signatures" and periodic comparisons with the actuator's real-time signatures as part of an advancement in fault prediction/isolation concepts.

4. Establish methods and size impacts for providing the retention of calibration curves for spare sensors in memory to be used following the replacement of a faulty sensor.

5. Evaluate the need and techniques for recording and storing operating parameters and conditions for each out-of-tolerance event occurring with ARS hardware. Focus shall be on the time preceding and following an out-of-tolerance event, allowing the data collected to be used for subsequent diagnostics.

REFERENCES

1. Popma, D. C., "Environmental Control System Development for Manned Spacecraft--1960-1973," presented at the Fourth Annual Intersociety Conference on Environmental Systems, Seattle, Washington, ASME Paper No. 74-ENAs-50, July 29-August 1, 1974.

2. Samonski, F. H. and Neel, J. M., "Atmosphere Revitalization for Manned Spacecraft - An Assessment of Technology Readiness," presented at the 24th IAF Congress, Baku, USSR, October, 1973.

3. Quattrone, P. D., "Spacecraft Oxygen Recovery System," Astronautica Acta, Volume 18, No. 4, October, 1973, pp. 261-272.

4. Ingelfinger, A. L. and Secord, T. C., "Life Support for Large Space Stations," presented at AIAA Fifth Annual Meeting, Philadelphia, Pennsylvania, October, 1968.

5. Schubert, F. H. and Quattrone, P. D., "Development of a Six-Man, Self-Contained Carbon Dioxide Collection Subsystem for Spacecraft Application," presented at the Fourth Annual Intersociety Conference on Environmental Systems, Seattle, Washington, ASME Paper No. 74-ENAs-16, July 29 - August 1, 1974.

6. Schubert, F. H. and Kostell, G. D., "Six-Man, Self-Contained Carbon Dioxide Concentrator Subsystem for Space Station Prototype (SSP) Application," Final Report, Contract NAS2-6478, NASA CR-114742, Life Systems, Inc., Cleveland, Ohio, March, 1974.

7. Willis, N. C., Jr. and Neel, J. M., "Space Prototype Environmental Thermal Control and Life Support System - A Current View," presented at the Second Annual Intersociety Conference on Environmental Systems, San Francisco, California, ASME Paper No. 72-ENAS-35, August 15-17, 1972.

8. Wynveen, R. A., Schubert, F. H. and Powell, J. D., "One-Man, Self-Contained CO_2 Concentrating System," Final Report, Contract NAS2-6118, NASA CR-114426, Life Systems, Inc., Cleveland, Ohio, March, 1972.

9. Powell, J. D. and Kostell, G. D., "Life Support Subsystem Monitoring Instrumentation," presented at the Fourth Annual Intersociety Conference on Environmental Systems, Seattle, Washington, ASME Paper No. 74-ENAs-25, July 29-August 1, 1974.

10. Schubert, F. H., Wynveen, R. A. and Hallick, T. M., "Integration of the Electrochemical Depolarized CO_2 Concentrator with the Bosch CO_2 Reduction Subsystem," Final Report, Contract NAS8-30891, ER-237-10, Life Systems, Inc., Cleveland, Ohio, March, 1976.

11. Schubert, F. H., Marshall, R. D., Hallick, T. M. and Woods, R. R., "One-Man Electrochemical Air Revitalization System Evaluation," Final Report, Contract NAS9-14658, ER-284-4, Life Systems, Inc., Cleveland, Ohio, July, 1976.

12. Schubert, F. H., Woods, R. R., Hallick, T. M. and Heppner, D. B., "Technology Advancement of the Electrochemical Carbon Dioxide Concentrating Process," Annual Report, ER-258-10, Life Systems, Inc., Cleveland, Ohio, May, 1977.

13. Heppner, D. B., Hallick, T. M. and Schubert, F. H., "Integrated Operation of a Bosch-Based Oxygen Recovery System," Final Report, Contract NAS8-30891, ER-237-11, Life Systems, Inc., Cleveland, Ohio, September, 1977.

14. See, G. G., Yang, P. Y. and Wynveen, R. A., "Development of Instrumentation for a Water Processing Element," Proceedings of the Third National Conference on Complete Water Reuse, Cincinnati, Ohio, June 27-30, 1976.

15. Yang, P. Y., See, G. G. and Yeh, J. Y., "A Minicomputer-Based Control and Monitor System for Water and Wastewater Treatment," Proceedings of International Computer Symposium, 1977, Volume 2, pp. 856-859, Taipei, Republic of China, December 27-29, 1977.